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OVERWATERING CONTROLLER

FOR LANDSCAPE IRRIGATION SYSTEMS

by

Paul Dominic Colaizzi

A Thesis Submitted to the Faculty of the

DEPARTMENT OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING

In Partial Fulfillment of the Requirements
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MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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Kenneth A. Jordan — 15 April 1997

Kenneth A. Jordan — Date

Professor of Agricultural and Biosystems Engineering

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DEDICATION

This thesis is hereby dedicated to my mother, Dr. Janet L. Colaizzi, Williamsburg, Virginia.

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ABSTRACT

Water conservation in metropolitan areas of Arizona is critical if limited water resources are to meet current and future demands. Timer controlled landscape irrigation systems contribute to a large portion of municipal water use, and there is currently a great potential for water savings when deficit irrigation is practiced. Such systems tend to forfeit deficit irrigation by overwatering vegetation; however, deficit irrigation may be improved if the number of irrigation cycles are reduced based on sensing soil water in the plant root zone. A patent pending electronic circuit, called the overwatering controller, has been developed and tested for this purpose. Test results show the overwatering controller has great potential as a water conservation and deficit irrigation management tool.

CHAPTER 1: INTRODUCTION

1.1 Arizona's Population Growth and the Need for Landscape Water Conservation

Arizona ranks as one of the fastest growing states in the nation; the population was 4.2 million in 1995, a 55 percent increase since 1980. By 2025, the population is expected to reach 6.4 million, a 52 percent projected increase which would make Arizona the forth most rapidly growing state. Arizona's population is about 80 percent urban; this proportion is also expected to increase in the next three decades (Campbell, 1996).

Recent and future population growth has and will place tremendous demands on Arizona's water resources. The municipal, industrial, and agricultural sectors have traditionally relied on mining groundwater; this has resulted in groundwater overdrafts in most metropolitan areas. In response to alarming drops in water table levels from overdrafts, the State of Arizona enacted the 1980 Groundwater Management Act. This Act resulted in the Arizona Department of Water Resources (ADWR) establishing four Active Management Areas (AMAs) where groundwater overdraft was the most critical. The four AMAs include Tucson, Phoenix, Pinal County, and Prescott. ADWR is charged with reducing groundwater reliance and encouraging

water conservation; the AMA goal is to eliminate aquifer overdraft by 2025.

Of the 2.5 million acre feet of AMA groundwater withdrawn in 1992, the industrial and municipal sectors accounted for 4 and 28.4 percent, respectively. The municipal portion, however, is increasing as agricultural land is converted to urban use. (ADWR, Conservation Requirements, 1993). Landscaping is a major portion of municipal water use; according to the Lawn Institute, up to 60 percent of municipal water is used for lawns in Western cities. Also, lawns cover more land in the United States than any other particular crop (*Resource*, May 1994).

The ADWR reports that a great potential for water conservation exists for irrigated landscaping in the industrial and municipal sectors. The practice of deficit irrigation has been found to be an effective conservation technique, but difficulties in predicting short term plant water use have prevented its widespread implementation. As a result, many landscape irrigation systems tend to overwater vegetation.

The justification of water use for landscaping is a political decision in the allocation of scarce resources and will not be argued here; however, landscape water conservation is important for Arizona's water resources.

The purpose of this study is to address water conservation and the possibility of deficit irrigation for landscape irrigation systems by using an electronic device called the overwatering controller. The overwatering controller senses soil water in the plant root zone with a soil probe; if soil water conditions are adequate, irrigation cycles are skipped. It is hypothesized that water conservation and deficit irrigation may be improved.

This research has three specific objectives. These are to develop and test the overwatering controller, to determine the optimal reference voltage setting within the electronic circuit that determines when irrigation cycles are skipped, and to quantify possible water savings. Although the original design objective of the overwatering controller was to simply conserve water, it appears possible to improve deficit irrigation. Actual evaluation of improvements in deficit irrigation, however, is beyond the scope of this study. Analysis of water savings will, nevertheless, suggest improvements in deficit irrigation.

With a grant from ADWR, Tucson Active Management Area (TAMA), fifty prototype overwatering controllers were built and tested at various locations around Tucson, Arizona.

The following sections discuss timer controlled landscape irrigation systems, deficit irrigation, and overwatering.

1.2 Timer Controlled Landscape Irrigation Systems

The vast majority of landscaped areas in both Arizona and the United States are irrigated with timer controlled landscape irrigation systems. These consist of a central timer controller and a number of individual irrigation stations. Each irrigation station has its own valve that is turned on periodically by the timer; the valve in turn allows water to flow to a set of water application devices such as sprinklers, bubblers, or emitters at the station. The valve at each station is activated by a 24 volt AC solenoid; wires run from the timer to the solenoids allow the timer to control watering for any desired frequency and duration (fig. 1.1). Most systems typically irrigate similar plant types with a station assigned for each watering requirement; each station is designed to serve a particular plant type.

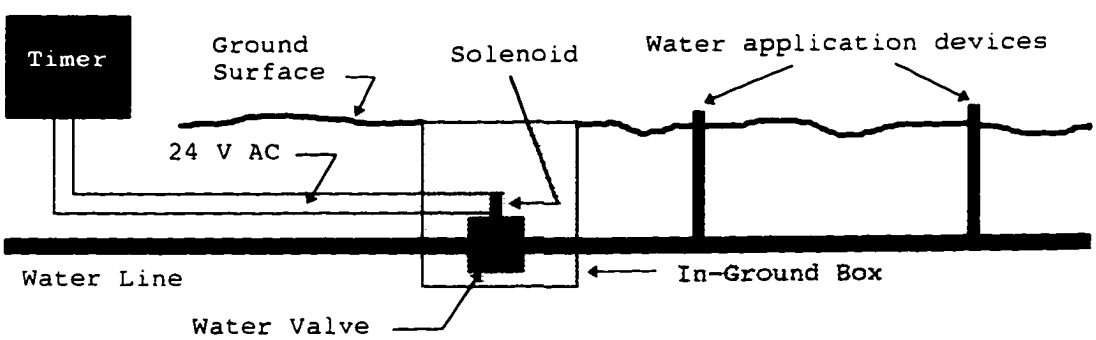

Figure 1.1: Landscape irrigation system showing a single station for similar plant types. Most systems control a number of stations independently.

Arizona's climate requires irrigation during most of the year and represents a large portion of municipal water use. Consequently, improvements in the efficiency of timer controlled systems can make a substantial contribution to municipal water conservation.

Much of the landscape vegetation found in Arizona, particularly Bermuda grass (*Cynodon dactylon*), is non-indigenous to the lower Sonoran deserts where urban areas are located. Annual precipitation averages (12 inches for Tucson and 9 inches for Phoenix) are well below plant water requirements. In addition, extreme high daytime temperatures, coupled with very low relative humidities, result in substantial vapor pressure deficits throughout much of the year. The growing season is also longer in Arizona's lower elevations. These factors increase water requirements for non-indigenous vegetation over those for the same species growing in other parts of the nation.

Other aspects of non-indigenous vegetation growing in Arizona are also worthy of mention. Plant species native to the lower Sonoran desert have adapted to extreme time and spatial variation of rainfall by the ability to store greater amounts of moisture than non-native plants. Native species generally have more extensive root systems to capture moisture when precipitation does occur.

Native species also have mechanisms to minimize moisture loss during the daytime when vapor pressure deficits are extreme. For most plants to carry out photosynthesis, stomata must be open to allow gas exchange, and transpiration (water loss) occurs. Transpiration rates depend on, among other things, vapor pressure deficits and plant water potentials; this rate is minimal at night when the vapor pressure deficit is minimal. Many native plants allow gas exchange at night and can store carbon dioxide needed for photosynthesis until daylight. The result is that stomata are closed during the day and open only at night, therefore minimizing moisture loss. Non-indigenous species used in landscaping, however, cannot store carbon dioxide and must open stomata to allow gas exchange during the day. This results in transpiration when vapor pressure deficits are at a maximum and increases water requirements.

The advantage of using timers to water large landscaped areas (*e.g.*, golf courses) is that it requires minimal labor. This is also true for small areas such as homes and businesses because watering can be done at night. Evaporative losses and disruption from spray are minimized. The main disadvantage is that deficit irrigation is difficult to maintain, and overwatering of vegetation is frequent. Overwatering may occur when timer-set irrigation frequencies and durations exceed plant water use, or if the

irrigation system has been poorly designed. Deficit irrigation and overwatering are defined in the following sections.

1.3 Deficit Irrigation

Deficit irrigation is the technique of maintaining the soil moisture content in the plant root zone below field capacity but safely above the wilting point. Field capacity is defined as the maximum soil moisture content where water will not drain by gravity. Permanent wilting point is defined as the soil moisture content where plants can no longer extract adequate moisture to maintain turgor. The plant root zone represents the portion of the soil moisture reservoir where plants can extract water.

For landscape vegetation and other agricultural crops, maximum water use efficiency (WUE) occurs when soil moisture is maintained in this range (James, 1988). WUE is defined as the ratio of the mass of plant dry matter produced to the mass of water used by the plant (Kramer and Boyer, 1995):

$$WUE = D / W \qquad (1.1)$$

where D = mass of plant dry matter produced

W = mass of water used by the plant.

Deficit irrigation improves WUE by, among other things, encouraging deeper root growth which in turn allows plants greater access to soil water. Also, the extended range of soil moisture depletion encourages growth of beneficial insects and other organisms while discouraging pests. It

has been reported that most operators of timer controlled irrigation systems in Arizona set irrigation cycles that result in only 10% soil moisture depletion. With deficit irrigation, however, up to 50% soil moisture depletion should be allowed (Waterfall, 1991).

1.4 Causes of Overwatering by Irrigation Systems

Overwatering of vegetation is defined herein as applying water at any time when the soil in the plant root zone is at field capacity. Overwatering eventually results in either deep percolation, or in more severe cases, runoff. Besides increasing water costs, overwatering can leach pesticides, fertilizers, and other nutrients below the root zone when deep percolation occurs. This may in turn contribute to groundwater contamination. When overwatering results in runoff, soil erosion may occur. It should be noted, however, that seasonal overwatering may be necessary to leach excessive salts from saline irrigation water away from the plant root zone.

There are two basic causes of overwatering by timer controlled systems. These are poor design and setting the timer to apply more water than needed at a given time. The former is a physical problem with an existing system; the latter is merely a management problem and can occur independently of the system design.

1.4.1 Overwatering Caused by Poor Design

It is desirable for water to reach a uniform depth over an area containing a plant type having a particular irrigation requirement. Thus, it is also desirable to group irrigation stations by plant types, and for each station to apply a uniform depth at the plant area. Distribution uniformity (DU) is a measure of how uniformly water is applied in an irrigated area, and poor DU is often a symptom of poor design.

Distribution uniformity (DU) is defined as "the ratio between some measure of the minimum depth intercepted and average depth intercepted" (Clemmens and Solomon, 1995). The "minimum depth" may be defined in any manner; it is usually the average depth in some defined fraction of the irrigated area (station) where the least amount of water is intercepted by plants. Mathematically, this is formulated as

$$DU = D_x / D_{avg} \qquad (1.2)$$

where D_x = average depth intercepted by plants in the x fraction of the irrigated area receiving the lowest depths

D_{avg} = average depth intercepted by plants in the entire irrigated area.

The "x fraction" is usually specified as 25%, or the low quarter, in agriculture. In this case, DU becomes the low quarter DU, or Du_{lq} (fig. 1.2a). If, for example, the average depth is 1.25 inches for the entire irrigated area, but in the quarter of the area receiving the least depth averages 0.75 inches, then Du_{lq} = 0.75/1.25 = 0.60.

The spacing of water application devices, line pressure, water delivery rates, ground slope, and soil infiltration characteristics affect DU. Figure 1.2b illustrates poor DU.

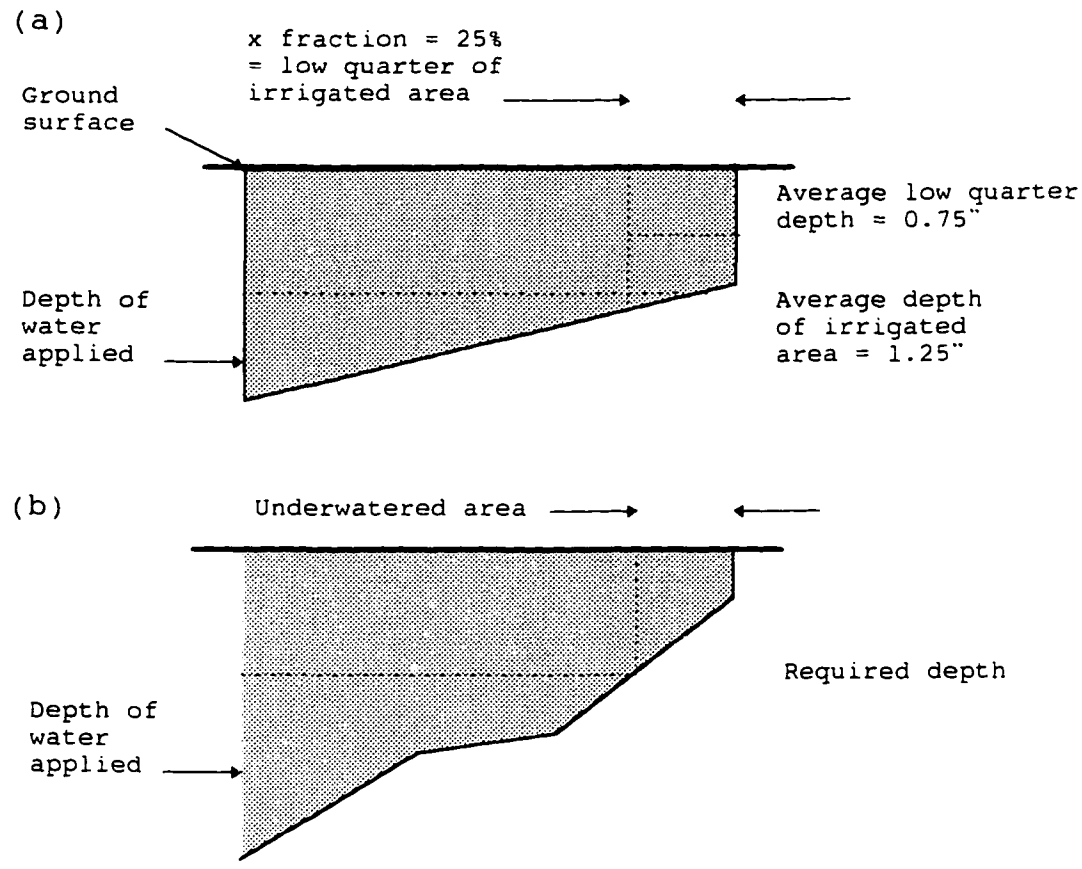

Figure 1.2:
(a) Irrigated area where low quarter DU = 0.60. (b) Poor DU.

This may be the result of either sprinklers spaced too far apart, inadequate sprinkler heads, or too much or too little line pressure for the particular model of sprinklers employed. The area underwatered may also be on a steep slope or have low soil infiltration, resulting in runoff to areas receiving greater depths of water where soil infiltration may be greater. In order to compensate for areas underwatered, frequency and duration of irrigations are often increased, resulting in overwatering over most of the station area.

Although it may be possible to actually improve DU by overwatering, this comes at the expense of application efficiency (AE). AE is defined as the ratio of the volume of irrigation water contributing to the irrigation requirement to the volume of irrigation water applied times 100% (Clemmens, et. al., 1995).

$$AE = V_{req} / V_{app} \qquad (1.3)$$

where V_{req} = volume of irrigation water contributing to the irrigation requirement x 100%

V_{app} = volume of irrigation water applied.

The best remedy for poor DU is to change the hardware. This may be as simple as changing sprinkler heads or line pressure, to changing sprinkler spacing which may require expensive and unsightly trenching.

1.4.2 Overwatering Caused by Management

The previous section pointed out that overwatering may occur to compensate for a poor design. Even with a well-designed system where DU has been maximized, however, and even if water is applied to closely match irrigation requirements to maximize AE, overwatering may still occur for two reasons.

First, it was mentioned that Arizona experiences extreme spatial and time variability of precipitation, quite typical of arid regions. Also, during summer monsoon months, storms occur in the afternoon and evening hours. Since managers of landscaped grounds usually set timers to apply water at night when they are not present, it is common for watering to occur during or following brief and localized heavy precipitation. Considering the number of stations and the expanse of a system under a single management, it is unfeasible to turn off the system where a rainfall event has occurred.

To address this problem, a water catchment pan with a rain sensor has been used. Should rain occur, the rain sensor shuts down the system until the water catchment pan becomes dry. Whereas this device may be good for public relations and does conserve water, it may result in underwatering if a rain event is adequate to trigger the rain sensor but inadequate to replenish the plant root zone.

Also, it does not address the second main cause of overwatering.

The second cause is inherently more difficult to overcome, even for the most conscientious managers of timer systems. It is the result of highly variable daily water consumptive use, or evapotranspiration. Evapotranspiration (ETa) is the sum of both plant transpiration and evaporation. Short term prediction of evapotranspiration is difficult to model; consequently, predictions for plant water requirements are based only on long term evapotranspiration averages. Evapotranspiration is usually modeled as the product of a "reference" evapotranspiration and a crop coefficient, or

$$ETa = ETr * Kc \qquad (1.4)$$

where ETr = Reference evapotranspiration

Kc = Crop coefficient.

Reference evapotranspiration is a function of weather conditions in the area; these include but are not limited to diurnal temperature, relative humidity, wind, cloud cover, and precipitation. The crop coefficient is a function of the growth stage, soil and water salinity, and growing degree days accumulated by the plant.

Figure 1.3 shows the variation of evapotranspiration as a function of time for a hypothetical Bermuda grass lawn. Depths of water application (irrigation cycles and rainfall events) are also shown that replenish the soil moisture reservoir in the root zone as it is depleted. If water applications minus evapotranspiration, deep percolation, and runoff were also plotted over time, a soil water balance results (fig. 1.4). The water application depths reflect timer settings to meet seasonal maximum plant water use. Although the soil moisture reservoir can serve as a buffer between field capacity and permanent wilting point for varying evapotranspiration, the soil water balance is often maintained around field capacity to ensure adequate moisture reserves during peak evapotranspiration. Consequently, temporary reductions in irrigation requirements result in soil moisture exceeding field capacity and therefore overwatering. Overwatering, however, has been a small economic consequence compared to risking an investment in landscape vegetation by underwatering. Furthermore, to match water applications to plant water use requires adjustment of timer settings weekly or even daily which is not practical. Therefore, timer settings are usually changed only monthly or seasonally.

In recent years, several irrigation equipment manufacturers have addressed the extreme short-term

variation of irrigation requirements by introducing software that link remote weather stations and soil moisture sensors to timer controllers. Such software allows continuous adjustment of timers and therefore water applications from a central computer. These systems may be advantageous to managers of large urban park systems or large golf courses; however, their costs may not be justifiable to homeowners or managers of small irrigated areas.

The overwatering controller addresses the difficulty of matching water applications to irrigation requirements for existing timer systems without the need for frequent timer adjustments or expensive remote sensing systems. Soil moisture conditions should ultimately determine when an irrigation takes place. By sensing these conditions, it is proposed that water may be conserved and deficit irrigation improved by merely skipping irrigation cycles when soil moisture is adequate to meet plant requirements until the next scheduled irrigation cycle (fig. 1.5). The overwatering controller was designed for this objective.

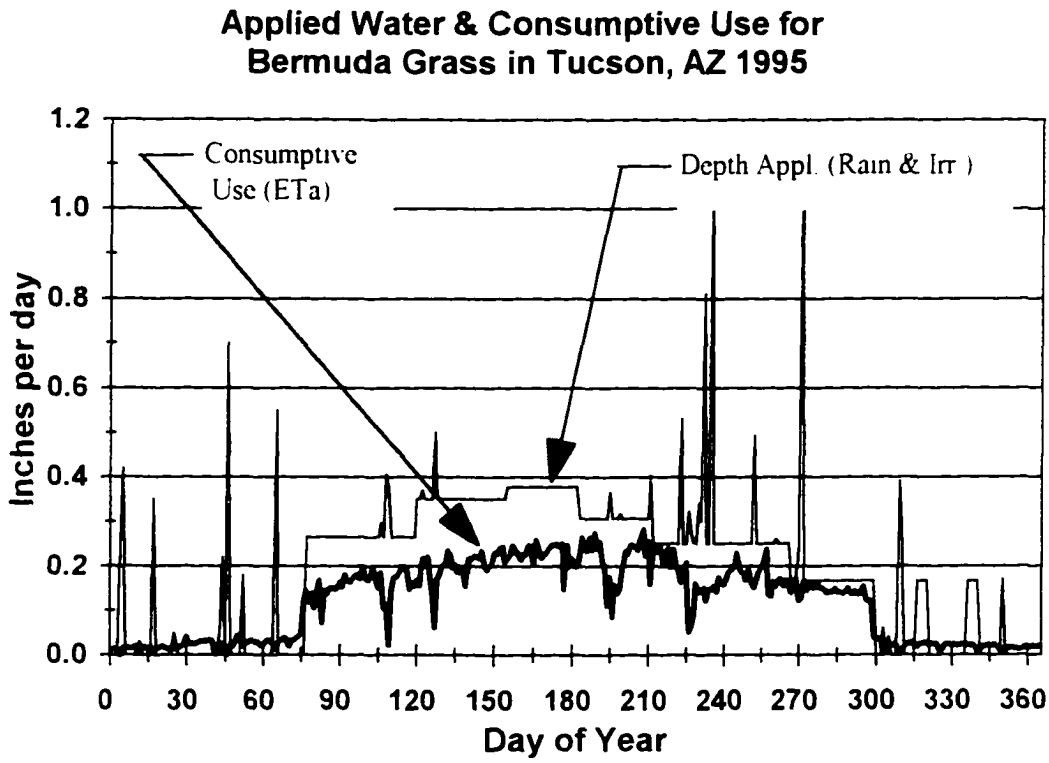

Figure 1.3: Applied water and consumptive use (ETa) vs. day of year for a hypothetical Bermuda lawn in Tucson, Arizona. Applied water includes both rain and irrigation. The upward "spikes" represent rainfall events; irrigation represents typical management practices in Tucson. ETa is the product of ETr and Kc. Note that the downward "spikes" in ETa often correspond to rainfall events when ETr is reduced. ETr, Kc, and rain are from 1995 data of the Arizona Meteorological Network (AZMET) Campus Agricultural Center in Tucson. Kc was assumed at 0.65 for Bermuda grass.

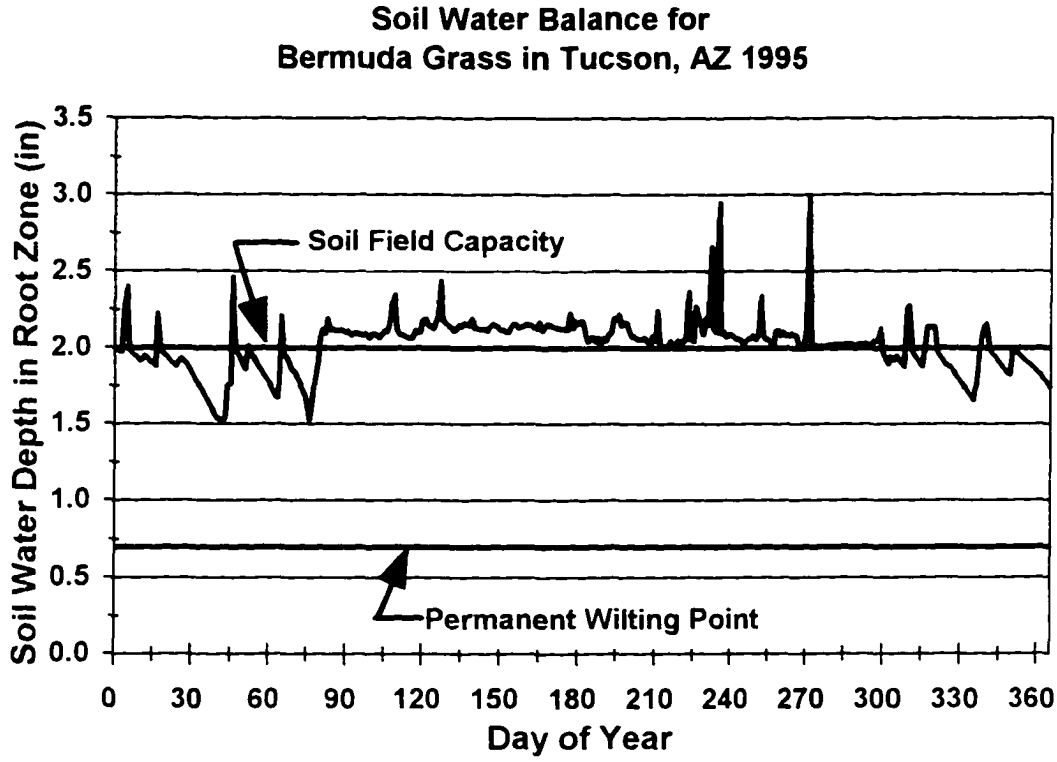

Figure 1.4: Soil water balance for the Bermuda lawn of fig. 1.3. The soil water depth is the cumulative sum of applied water (rain and irrigation) minus ETa, deep percolation, and runoff. Overwatering is represented when the soil water depth exceeds field capacity. The upward "spikes" represent rainfall events. The soil is a sandy loam of Pima County, Arizona, where soil water holding capacity (field capacity) is 2 in. (50 mm) for the first 1 ft. (30 cm) depth (Fox, et. al., 1992), and 1 ft. (30 cm) was assumed to be the depth of the plant root zone where water may be extracted. The permanent wilting point was arbitrarily assumed to be 0.7 in. (18 mm).

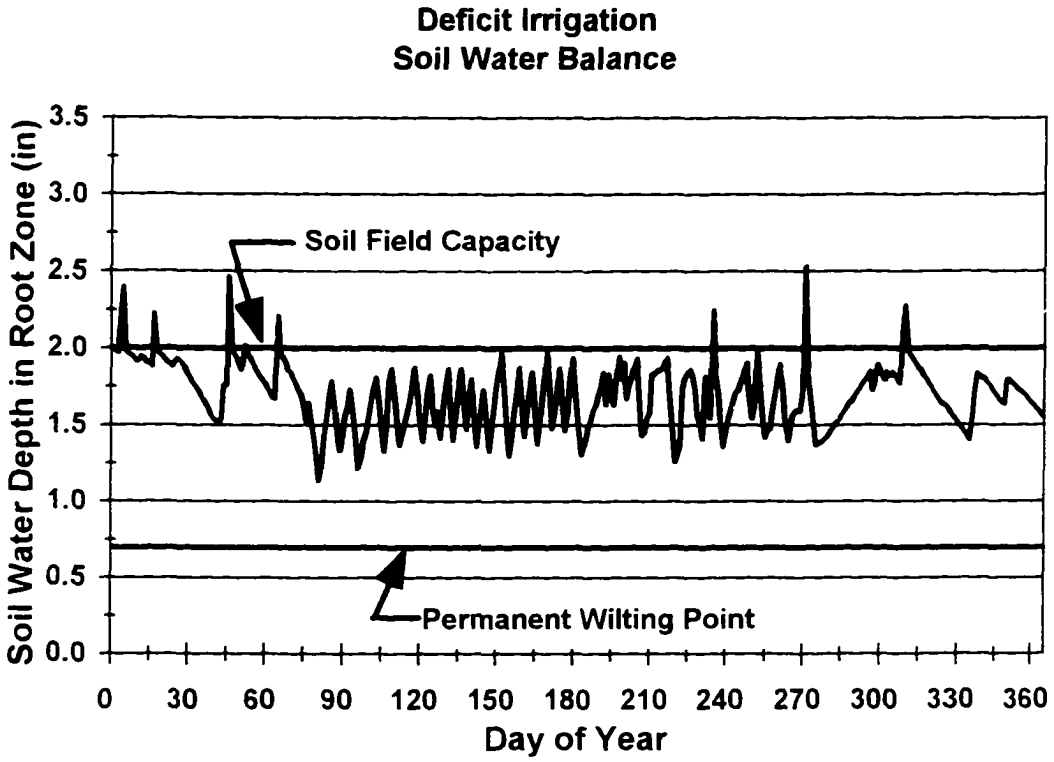

Figure 1.5: Deficit irrigation for the soil water balance of figure 1.4. Deficit irrigation was achieved by merely skipping certain irrigation cycles without changing the timer setting. Soil moisture was allowed to cycle between field capacity and safely above the permanent wilting point. This illustrates the possibility of improving deficit irrigation by using the overwatering controller.

CHAPTER 2: OBJECTIVES

The general objective of this research is to address overwatering of landscape vegetation using a device called the overwatering controller. Reductions in overwatering can result in both water conservation and improvements in deficit irrigation.

In order to reduce overwatering, it is proposed that an irrigation cycle should be allowed only if the soil moisture reservoir has been depleted below a certain level. The overwatering controller has been developed for this objective.

The overwatering controller consists of an electronic circuit and a soil probe. At the beginning of an irrigation cycle, the overwatering controller should sense soil moisture conditions. An irrigation cycle should be skipped if the soil would otherwise be brought to field capacity; if the soil would fall to the plant wilting point before the next irrigation cycle, an irrigation would be allowed. The reference point of the soil probe should be adjustable to allow for different plant water requirements and soil and water compositions.

This research therefore has three specific goals; these are to develop and test overwatering controllers installed in stations of timer controlled landscape irrigation systems, to determine the optimal adjustment of the soil

probe reference point based on visual plant responses, and to quantify water savings at test stations.

Although improvement of deficit irrigation appears possible using the overwatering controller, actual evaluation of deficit irrigation is beyond the scope and funding of this research. Such an evaluation would require continuous measurement of soil moisture content, as well as knowledge of soil water holding capacity and moisture depletion at the plant wilting point. The soil probe of the overwatering controller merely *senses* soil moisture *conditions* at the *beginning* of an irrigation cycle as opposed to *continuous measurement* of water *content*. Comparison of plant water use and water applied in terms of depths may, however, imply improvements in deficit irrigation. These comparisons will also be addressed.

CHAPTER 3: OVERWATERING CONTROLLER DESIGN AND OPERATION

3.1 Overview

Given the spatial and time variability of plant water requirements, overwatering and deficit irrigation should be addressed on as local a scale as possible, *i.e.*, individual irrigation stations. One overwatering controller unit is therefore installed per station and monitors soil moisture conditions *in situ*.

Figure 3.1 illustrates the electronic circuit and soil probe components of the overwatering controller. The electronic circuit is placed in the station valve box and activates the valve solenoid. The soil probe is placed in a "representative" station area. Placement criteria of the soil probe will be discussed later. The buried soil probe and wires are connected to the electronic circuit.

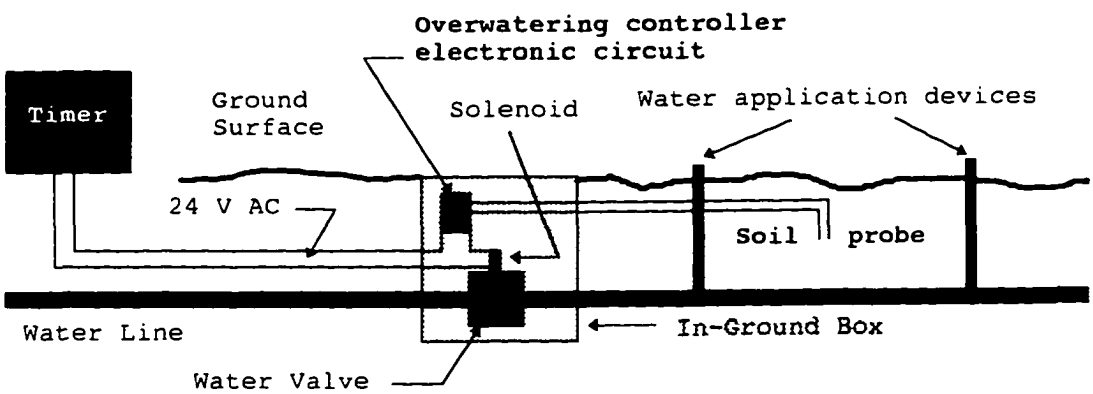

Figure 3.1: Overwatering controller design concept.

When an irrigation cycle is scheduled for a station, the circuit is energized with a 24 V AC signal. This voltage activates the overwatering controller which senses the soil moisture condition. If water is to be applied during this cycle, the solenoid is energized and the irrigation begins. If the irrigation would bring the soil at or above field capacity, however, the irrigation event is skipped. A counter on the overwatering controller is activated to record the skipped cycle, and the solenoid is not activated.

The soil probe senses the electrical conductivity in the soil which is a function of moisture content. The probe consists of two copper cap electrodes spaced a fixed distance apart. Leads are soldered to the caps and connected to the electronic circuit (fig. 3.2).

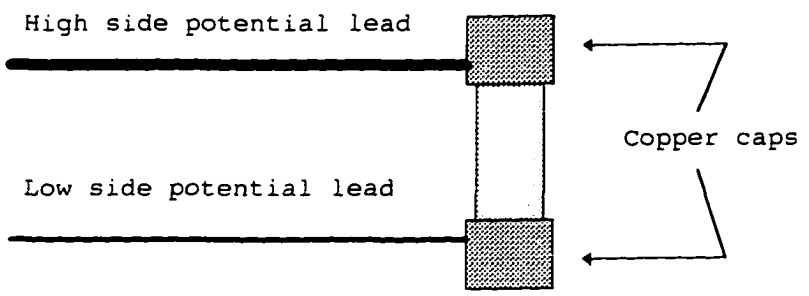

Figure 3.2: Soil probe.

One cap is maintained at a fixed potential, defined here as the "high side." The potential of the other cap, defined here as the "low side," will be less than the high side potential depending on soil moisture present. The drier the soil, the lower the potential will be on the low side of the soil probe.

The electronic circuit of the controller "reads" the low side potential which is compared to a reference voltage within the circuit (fig. 3.3).

If the low side potential exceeds the reference voltage (indicating high soil water conditions at the soil probe as in fig. 3.3a), the overwatering controller will prevent activation of the solenoid during the cycle. Watering will not be allowed until later cycles, provided soil moisture has been depleted to warrant an irrigation. If moisture is below the level allowing irrigation (fig. 3.3b), watering will take place for the entire duration of the cycle.

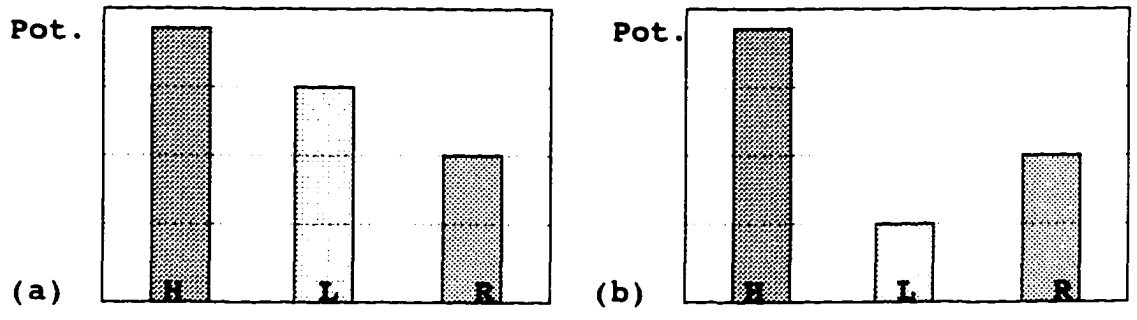

Figure 3.3: **H** = high side, **L** = low side, **R** = reference voltage potentials. (a) High soil moisture content. (b) Low soil moisture content.

The reference voltage may be easily adjusted in the field with a screw driver; hence, the soil water content at which watering is allowed or prevented can be adjusted. For ease of installation, the controller is passive; thus, it can be wired to existing irrigation timer circuits and does not require its own separate power source. In this way, it takes advantage of the 24 V AC power already present when the timer energizes a station.

It is important to note at this point that the overwatering controller is not intended to correct poor distribution uniformity resulting from a poor irrigation system design. Rather, it is intended as a water management tool where there is the possibility of improving application efficiency and water use efficiency. Indeed, the overwatering controller even may aggravate already poor irrigation system performance; as stated previously, this is best addressed through attention of the hardware.

3.2 Modes of Operation

With an overview of the overwatering controller given, three "modes of operation" can be defined to help clarify the circuit design, operation, and testing procedure.

Mode A

Operational Mode A of the overwatering controller is defined as the low side potential of the soil probe being less than the reference voltage (fig 3.3b), indicating a relatively dry soil. This occurs when the timer first energizes the station. Since the soil probe low side potential is less than the reference voltage, the overwatering controller completes the timer-to-solenoid circuit. The station valve is then opened and an irrigation cycle begins.

Mode B

After Mode A begins and the soil is receiving water, the soil probe low side potential gradually increases above the reference voltage (fig 3.3a) as the wetting front reaches the soil probe. At this instant, the overwatering controller enters Operational Mode B. Although the low side potential has now exceeded the reference voltage, the overwatering controller does not open the timer-to-solenoid circuit, and the irrigation cycle follows through to completion. The circuitry to accomplish completing the irrigation event is discussed in Appendix A.

Mode C

If the soil probe low side potential is greater than the reference voltage (fig. 3.3a) at the *beginning* of the irrigation cycle, soil water content is sufficient and does not warrant the irrigation cycle. The overwatering controller maintains an open timer-to-solenoid circuit during the cycle, preventing watering at the station. This is defined as Operational Mode C. Watering will not occur until a subsequent cycle when the overwatering controller begins in Mode A.

3.3 Circuit Design

The circuit of the overwatering controller can be divided into five sub-circuits. These are defined as (1) soil probe and comparitor; (2) NAND gate flip-flop; (3) pulse counter; (4) solid state relay; and (5) power converter.

The circuit design concept of the overwatering controller originated with a circuit appearing in the *Encyclopedia of Electronic Circuits* (Graf, 1988). The present design is based on the comparitor and the NAND gate flip-flop of the original circuit. Each sub-circuit is illustrated and explained in detail in Appendix A. The complete circuit is shown in Figure 3.4.

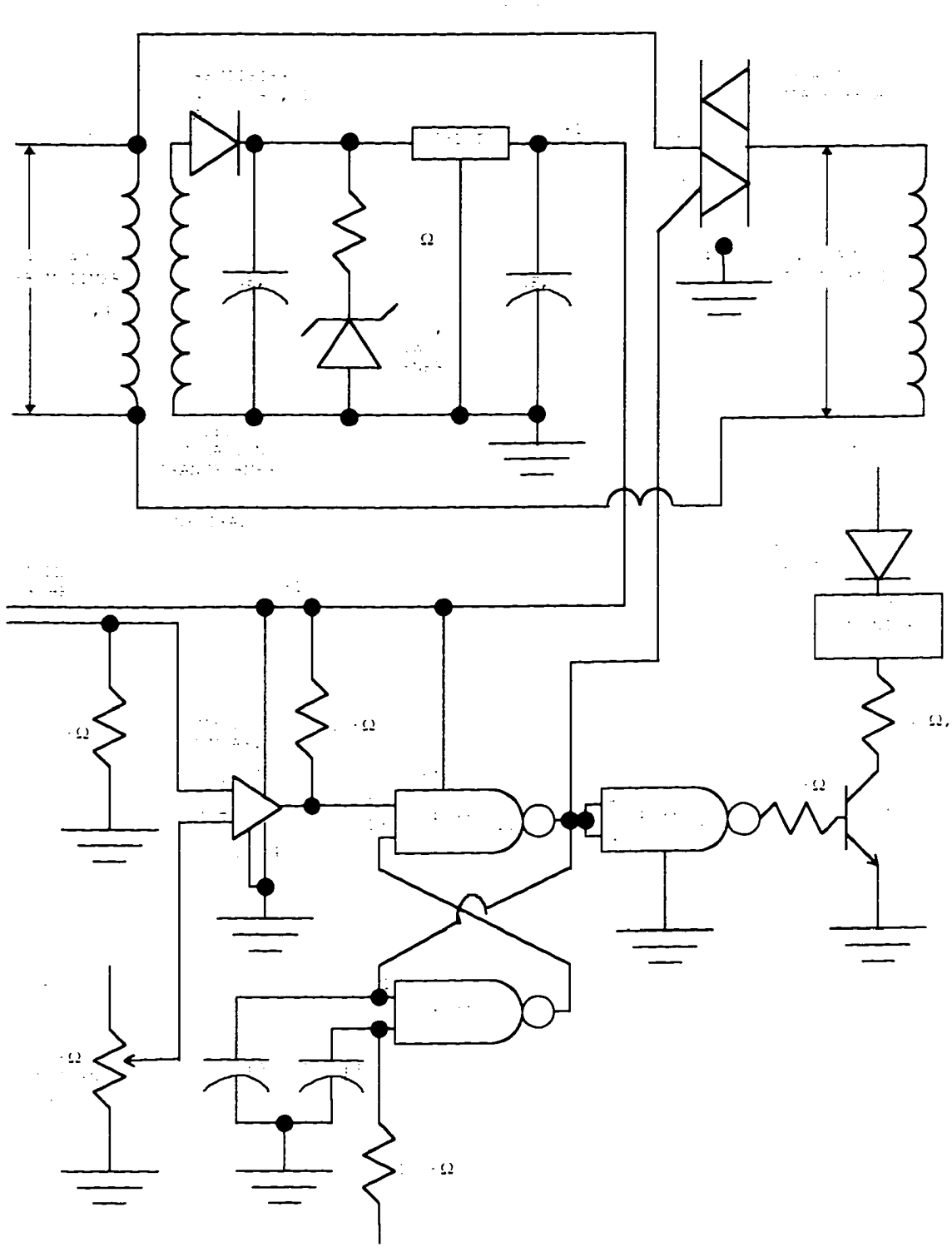

Figure 3.4: Overwatering controller schematic diagram.

CHAPTER 4: RESEARCH METHODS

4.1 Overwatering Controller Test Sites

Fifty overwatering controller prototypes were installed at sites around the Tucson, Arizona area for testing during the 1996 growing season. These test sites include four private residences, one apartment complex, two city parks, six county parks, three elementary schools, and the Reid Park Zoo. A special installation procedure was employed at the schools (see Appendix B). Each site was visited at least weekly for data collection, inspection, and to ensure proper operation of the overwatering controllers. Problems, if any, were discussed with irrigation system operators during each visit.

The test sites were spread out over much of the city to provide a variety of environments, irrigation system types, plants, and irrigation management practices. Of the fifty overwatering controllers tested, thirty seven (37) were tested at sprinkler stations, five (5) at bubbler stations, and eight (8) at emitter stations. All of the sprinkler stations contained Bermuda grass (*Cynodon dactylon*), except for two stations at Sunset Park where Buffalo grass (*Buchloe dactyloides*) was planted. Eight (8) sprinkler stations were re-seeded with ryegrass (genus *Lolium*) during October. The remaining bubbler and drip emitter stations contained trees and shrubs.

Appendix D summarizes the test sites according to cooperating agency and the number of overwatering controllers installed and contains further technical information on these sites.

4.2 Data Collection

Data collected consisted primarily of pulse counter readings each week. Each pulse count represents the number of irrigation cycles that were skipped since the previous reading. For each station, the frequency and duration of irrigation cycles per week were known as set by the timer. Also, flowrates to each station were estimated based on sprinkler, bubbler, and drip emitter specifications of the manufacturer, and irrigation system water line pressure estimates obtained from each site representative (see Appendix D). With this information, the quantity of water saved may be estimated as

$$S = Q * T * PC \qquad (4.1)$$

where S = Water saved (gallons)

Q = Station flowrate (Gallons per minute)

T = Station cycle duration (minutes)

PC = Number of pulse counts per week (irrigations skipped).

The overall volume of water that potentially would have been applied per week at the station (without the overwatering controller installed) may be estimated as

$$V = Q * T * F \qquad (4.2)$$

where V = Potential volume to be applied (gallons)

F = Frequency (number of irrigation cycles)

and all other terms are as previously defined.

Actual water applied using the overwatering controller is then found by subtracting S from V.

For sprinkler stations, it was possible to estimate weekly irrigation requirements in terms of depth for the various types of grass. The irrigation requirements could then be compared to depths potentially applied and actually applied over weekly intervals. These comparisons may suggest improvements in matching irrigation depths actually applied to the irrigation requirements of grass using the overwatering controller. This in turn can imply reductions in overwatering and improvements in deficit irrigation.

Irrigation depths potentially applied and actually applied were estimated using equations 4.1 and 4.2, except the sprinkler application rate (depth applied per unit time) was substituted for the flowrate Q. Application rates were estimated in the same manner as flowrates (see Appendix D).

The irrigation requirement is defined in this study simply as the *total* depth of water required to meet plant water use (evapotranspiration), minus precipitation, over a weekly interval. The leaching requirement is not

considered. Note that the irrigation requirement is defined in terms of a weekly total; this is without regard to the timing and depths of single irrigation events during the week. This was necessary because the parameters that affect requirements of single irrigation events could not be evaluated during this study. Such parameters include the soil water holding capacity, soil infiltration characteristics, allowable soil water depletion, deep percolation, and runoff.

Total weekly irrigation requirements at sprinkler stations were estimated using reference evapotranspiration (ETr) and precipitation data from the Arizona Meteorological Network (AZMET). The AZMET data recording station for Tucson is located at the University of Arizona Campus Agricultural Center (CAC) in the north central part of the city. In calculating evapotranspiration (ETa) for the sprinkler stations using equation 1.4, AZMET recommends a crop coefficient (Kc) of 0.65 for acceptable quality Bermuda grass typically found at parks and schools. For high quality Bermuda grass typically found at golf courses, homes, and apartments, a crop coefficient of 0.75 is recommended. These crop coefficient values were also assumed for ryegrass and Buffalo grass.

Comparisons of depths applied and depths required were not considered for the bubbler and emitter stations.

Difficulties in estimating depth application rates and lack of crop coefficient data for trees and shrubs at these stations precluded such an analysis; consequently, only volumes of water saved were considered.

This method of estimating water quantities used and saved should be viewed only as an estimate at best. Line pressure in municipal water delivery systems vary with demand, and most sprinklers are not pressure compensating. Consequently, flow rates at stations vary with working line pressure. Also, manufacturer's specifications of sprinklers, bubblers, and emitters reflect flow rates for the new condition of the device. Many irrigation systems encountered were quite old, however, and it is likely that not all components were performing optimally. For example, hard water deposits may have reduced flow rates.

A more precise method of quantifying water used and saved is to simply install flow meters directly at the station valves. This was the original method intended when this research was in the planning stages. Test stations with the overwatering controller installed would be compared to a similar control station without the controller. Flowmeters would have been installed at both the test and control stations. Most of the station water lines, however, were of sufficient size (2 inches to 4 inches) that very

expensive flow meters would have been required, and this clearly would have exceeded the budget.

Knowing the number of irrigation cycles skipped does, none the less, provide an estimate of the percentage of water savings possible by using the overwatering controller. Appendix F contains data for the depths applied and depths required at the sprinkler stations.

4.3 Criteria for Reference Voltage Adjustment

Whenever possible, test stations with the overwatering controller installed had a companion control station. The control station had the same vegetation and similar sprinkler, bubbler, or emitter models as the test station. Reference voltage adjustment was based on visual observations of plant response. Most of the reference voltages were initially set at 9 or 10 volts. If vegetation at the test station appeared more water stressed or wilted than that of the control station, the reference voltage was increased. Also, soil at test stations were inspected by touch for excessive dryness compared to soil at the control station. This provided additional criteria for adjusting the reference voltage.

At sites where a control station was not available, plant and soil conditions were noted if they differed from other sites having the same vegetation. In any case, close contact was maintained with the irrigation system operator concerning plant response. Final reference voltage settings are tabulated in Appendix E.

CHAPTER 5: RESULTS AND DISCUSSION

Overwatering controllers were first installed at test stations during May, June, and July 1996. The original overwatering design had to be modified, however, to prevent stray voltage in the ground from interfering with the soil probe potentials so that irrigation cycles would be skipped (see Appendix A). The modified designs were installed during August and September 1996, and it was not until then that any appreciable water savings was documented. Data analysis therefore spans only September, October, and the first half of November 1996.

Of the thirty seven sprinkler stations where overwatering controllers were tested, six stations were excluded from the data analyses because of operational difficulties. These include the Louy residence, the Mullaney residence, two stations at Las Palmas Apartments, and two stations at the Reid Park Zoo. Timers at several stations often malfunctioned unless the overwatering controllers were either disconnected or the reference voltages were set too high to allow any irrigation cycles to be skipped. In other cases, no irrigation cycles were skipped despite obvious overwatering and reasonable reference voltage settings. The exact causes of these difficulties were not determined; however, it is suspected that some incompatibility existed between the timers and

operational Mode C of the overwatering controller circuit. Overwatering controllers generally functioned properly at the remaining thirty one sprinkler stations, five bubbler stations, and eight emitter stations.

The results presented in this chapter consist of two sections. The first section includes a discussion of volumes saved, actually applied, and *potentially* applied; *i.e.*, the quantity that would have potentially been applied at test stations without the overwatering controller installed. The second section presents a comparison of depths potentially applied to weekly irrigation requirements at sprinkler stations, as well as a comparison of depths actually applied to weekly irrigation requirements. The comparisons show that depths potentially applied tended to be in excess of weekly irrigation requirements, whereas the depths actually applied tended to be below weekly irrigation requirements. This implies that overwatering was likely reduced and deficit irrigation may have been improved at the sprinkler stations.

Comparisons were performed using the Wilcoxon signed rank test for paired data (Scheaffer and McClave, 1990). This is a distribution-free alternative to the "t" test where two treatments are tested for differences (Milton, 1992). All tests were conducted at the 0.90 level of significance.

5.1 Comparison of Volumes and Cycle Times

Potential volumes that would have been applied by timer settings and actual volumes allowed by the overwatering controller were compared for all weekly readings of all stations. Weekly readings of sprinkler, bubbler, and emitter stations were also compared. Use of the overwatering controller resulted in water savings in all cases, most of which were at sprinkler stations. When only bubbler stations were analyzed, however, no statistically significant difference was found between applied and potential volumes. Water savings are summarized in Table 5.1.

Since flowrates at test stations varied from less than 10 gpm to over 100 gpm, the proportions of the volumes are biased. Therefore, skipped, allowed, and potential cycle times were also compared; these are summarized in Table 5.2. Statistical analysis of differences between allowed and potential cycle times were identical to their volume counterparts.

Volumes and cycle times for individual stations are tabulated in Appendix F.

Table 5.1: Summary of water savings during Fall 1996 (total gallons).

Irrigation Method	Saved	Applied	Potential	Percent Savings
Sprinklers (n = 31)	340,800	608,570	949,370	**35%**
Bubblers (n = 5)	26,430	84,440	110,870	**25%**
Emitters (n = 8)	15,020	46,800	61,820	**25%**
Totals	**382,250**	**739,810**	**1,122,060**	**35%**

Table 5.2: Summary of skipped irrigation times during Fall 1996 (total minutes).

Irrigation Method	Irr. Times (min) Skipped	Potential	Percent Skipped	Mean	Med.
Sprinklers (n = 31)	7,760	20,000	40%	35%	35%
Bubblers (n = 5)	740	3,170	25%	20%	25%
Emitters (n = 8)	7,100	26,830	25%	25%	20%
Totals	**15,600**	**50,000**	**30%**	**30%**	**30%**

5.2 Analyses of Depths at Sprinkler Stations

Comparison of irrigation depths potentially applied (without the overwatering controller) to weekly irrigation requirements, as well as irrigation depths actually applied (as allowed by the overwatering controller) to weekly irrigation requirements, are analyzed in this section. Weekly irrigation requirements for this study are defined in Section 4.2. Although overwatering as defined in Section 1.4 cannot be directly evaluated, overwatering is implied when potential and actual irrigation depths applied are in excess of weekly irrigation requirements.

The comparison of these parameters were done in the following manner. For all weeks and all sprinkler stations considered (229 data points), potential irrigation depths were compared to the corresponding weekly irrigation requirement. Using the Wilcoxon signed rank test, it was found that the median of all potential irrigation depths was 0.3 inches *above* the median of all weekly irrigation requirements. This implies that overwatering probably would have occurred without using the overwatering controller. Similarly, actual irrigation depths applied were compared to weekly irrigation requirements; the former median was 0.3 inches *below* the latter median. This implies that overwatering was reduced and deficit irrigation may have been improved when the overwatering controller was used.

Next, for all weeks and all sprinkler stations considered (229 data points), potential irrigation depths minus weekly irrigation requirements are ranked in order and plot (figure 5.1). The corresponding actual depth applied minus the weekly irrigation requirement is also shown.

Figure 5.1 raises the following three questions about the performance and adjustment of the overwatering controller. These include

(1) In cases where the potential irrigation depth was *below* the weekly irrigation requirement (negative "potential depth minus requirement" in figure 5.1), did using the overwatering controller result in needlessly reducing depths actually applied even further?

(2) In cases where the potential depth greatly exceeded the weekly irrigation requirement, to what extent was the actual depth applied above or below the weekly irrigation requirement?

(3) What role did precipitation play where the potential depth greatly exceeded the weekly irrigation requirement?

The first two questions are addressed by considering the overall range between potential depths minus weekly irrigation requirements; this parameter ranges from -1.0 to 4.2 inches per week. Four subset ranges are then considered; these are -1.0 to 0, 0 to 1.0, 1.0 to 2.0, and 2.0 to 4.2 inches per week. For each subset range, the same

Wilcoxon signed rank test is performed where the actual applied depth is compared to the weekly irrigation requirement. Results of these tests are summarized in Table 5.3.

It can be seen that for the first range (-1.0 to 0 inches per week), the median actual applied depth was 0.3 inches *below* the median weekly irrigation requirement. This was also the median difference between potential depth and the weekly irrigation requirement. The overwatering controller therefore did not significantly reduce depths actually applied in this range.

In the second range (0 to 1.0 inches per week), the median actual applied depth was also 0.3 inches *below* the median weekly irrigation requirement. The median potential depth, however, was 0.4 inches *above* the median weekly irrigation requirement.

In the third range (1.0 to 2.0 inches per week), the median actual applied depth was 0.8 inches *above* the median weekly irrigation requirement. The median potential depth was 1.3 inches *above* the median weekly irrigation requirement.

In the forth range (2.0 to 4.2 inches per week), the median actual applied depth was 0.5 inches *above* the median weekly irrigation requirement. The median potential depth

was 2.6 inches *above* the median weekly irrigation requirement.

These results again show that using the overwatering controller reduced irrigation depths actually applied compared to irrigation depths potentially applied (without using the overwatering controller). Furthermore, the overwatering controller resulted in a closer match between the irrigation depths actually applied and weekly irrigation requirements. In cases where depths actually applied remained above weekly irrigation requirements, the third question must now be addressed. Restated, this is the role that precipitation played where depths potentially applied exceeded weekly irrigation requirements.

A similar set of comparison tests were conducted, except precipitation was excluded from estimates of weekly irrigation requirements. This resulted in irrigation requirements simply being assumed equal to evapotranspiration. Results of the comparison tests are summarized in Table 5.4. The median of all potential depths was 0.1 inches *above* the median weekly evapotranspiration; however, the median of all depths actually applied was 0.3 inches *below* the median weekly evapotranspiration.

The same data from figure 5.1 is plot in figure 5.2, excluding rainfall. Potential depths applied minus evapotranspiration ranged from -1.0 to 3.8 inches per week.

Three subset ranges of this parameter were then considered; these were -1.0 to 0, 0 to 1.0, and 1.0 to 3.8 inches per week. For all ranges, the medians of depths actually applied were 0.3 inches *below* the median weekly evapotranspiration (Table 5.4).

Comparison of Table 5.3 to Table 5.4 suggests that precipitation indeed affected the cases where the potential depth was greater than 1.0 inches above the weekly irrigation requirement. Since runoff and deep percolation could not be quantified for rainfall events, it was assumed that *all* precipitation contributed in reducing irrigation requirements. Considering soil characteristics and rainfall patterns at the test locations, however, it is likely that the benefits of precipitation were reduced, and weekly irrigation requirements were therefore underestimated when precipitation was involved. This in turn means that for the comparisons where precipitation is included (Figure 5.1 and Table 5.3), potential depths minus irrigation requirements and depths actually applied minus irrigation requirements may be overestimated. This is in cases where the former parameter exceeded 1.0 inches per week.

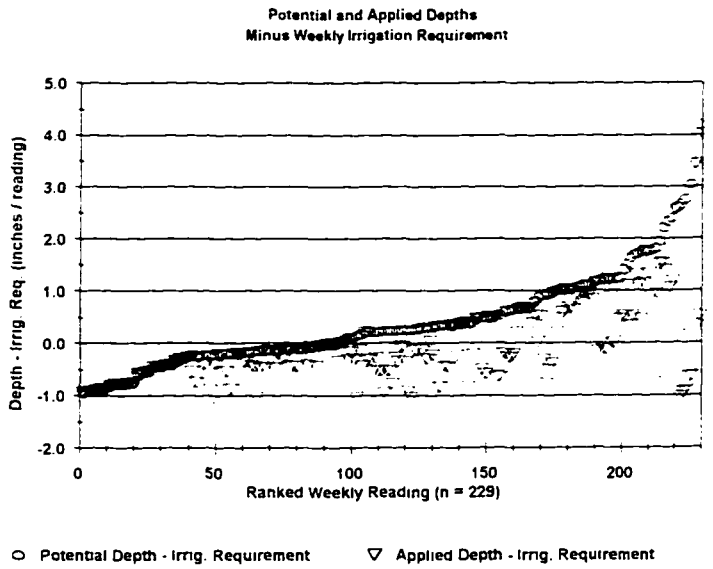

Figure 5.1: Irrigation depths potentially applied minus weekly irrigation requirements (evapotranspiration minus precipitation) ranked in order, with corresponding depths actually applied minus weekly irrigation requirements. All weeks and all sprinkler stations.

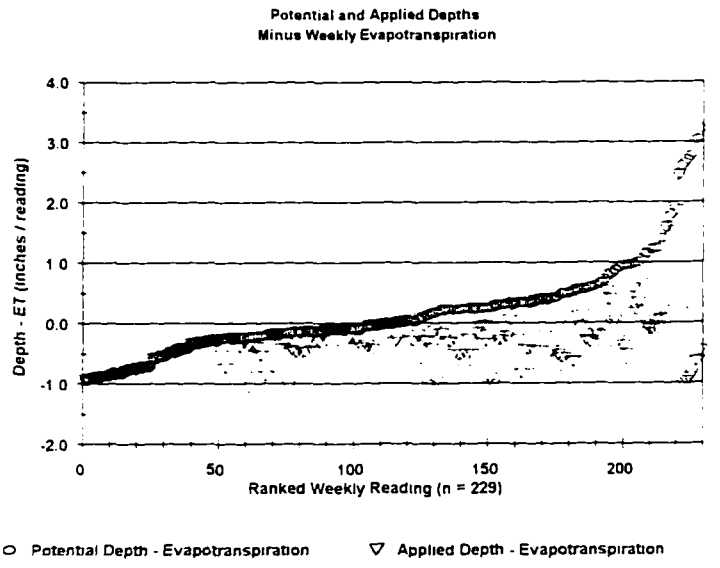

Figure 5.2: Irrigation depths potentially applied minus weekly evapotranspiration (irrigation requirements excluding precipitation) ranked in order, with corresponding depths actually applied minus weekly evapotranspiration. All weeks and all sprinkler stations.

Table 5.3: Summary of data from Figure 5.1. α = 0.10. Columns are as follows:

(A) Irrigation depths potentially applied (without the overwatering controller) minus weekly irrigation requirements (evapotranspiration minus precipitation); considering various ranges of this parameter.

(B) Medians for various ranges of column (A).

(C) Medians for depths actually applied (as allowed by the overwatering controller) minus weekly irrigation requirements (evapotranspiration minus precipitation); corresponds to various ranges of column (A).

A (in/wk)	B (in/wk)	C (in/wk)	Number of Weekly Readings
-1.0 to 0.0	-0.3	-0.3	95
0.0 to 1.0	0.4	-0.3	80
1.0 to 2.0	1.3	0.8	39
2.0 to 4.2	2.6	0.5	15
All Ranges (-1.0 to 4.2)	0.3	-0.3	229

Table 5.4: Summary of data from Figure 5.2. Parameters (A), (B), and (C) are identical to those in Table 5.3, except precipitation is excluded. Weekly irrigation requirements therefore are assumed equal to weekly evapotranspiration. α = 0.10.

A (in/wk)	B (in/wk)	C (in/wk)	Number of Weekly Readings
-1.0 to 0.0	-0.3	-0.3	115
0.0 to 1.0	0.3	-0.3	91
1.0 to 3.8	1.8	-0.3	23
All Ranges (-1.0 to 3.8)	0.1	-0.3	229

CHAPTER 6: RECOMMENDATIONS

Four recommendations will be made for future studies of the overwatering controller. These include a modification to the soil probe, placement of the soil probe, improvements to the water resistance of the circuit housing, and a modification of the circuit.

6.1 Soil Probe Modification

The copper cap contacts of the present soil probe are spaced two inches apart. Using this spacing, the reference voltage should be set initially at 9 volts for sites irrigated with potable water and 11 volts for sites irrigated with reclaimed water. These reference voltage settings imply that the low side potential did not decrease much below 12 volts as plants withdrew soil moisture. Indeed, when overwatering controllers were tested occasionally (see Appendix C for the testing procedure), the low side potential was frequently observed at around 11 volts. Consequently, it appears that the soil moisture condition at which an irrigation cycle was skipped was very sensitive to reference voltage adjustments.

It is proposed that by increasing the copper cap spacing, the low side potential will decrease more as soil moisture is depleted. This will in turn decrease the sensitivity of reference voltage adjustments. The copper cap spacing should therefore be increased to 4 inches or

more, depending on soil and water salinity of the site. The low side potential of the soil probe should be monitored continuously for several copper cap spacings as soil moisture conditions fluctuate. A new spacing should be selected based on observed low side potentials that decrease to around, say, 6 volts when the management allowed depletion of soil moisture has been reached.

6.2 Soil Probe Placement

During this study, the depth of the soil probe was kept at 4 to 6 inches from the surface. It is not known how varying the soil probe depth would affect performance of the overwatering controller or plant response; however, this should be investigated as well.

In arid regions, evaporation is thought to be a major component of evapotranspiration. Assuming this causes soil moisture depletion to progress downward from the surface, it is possible that burying the soil probe deeper will allow more moisture to be depleted from root zones. This may stimulate deeper root growth, and vegetation could have access to a larger soil moisture reservoir. This would allow a greater buffer zone as plant water use varies, as well as landscape vegetation more resistant to pests and storm damage.

6.3 Circuit Housing Water Resistance

Overwatering controller circuits were installed in control valve boxes of irrigation systems, and these are very moist environments. The boxes are also subject to becoming completely submerged following heavy rainfall events as they are placed below the surface. In many cases, the circuit housing used (see Appendix B) proved to be a rather crude method of protecting the circuit from moisture, especially at sites in the path of heavy runoff. Circuits at a few sites had to be replaced repeatedly as corrosion destroyed leads on the boards.

It is clear that the circuit housing should be made more water resistant, but without sacrificing accessibility for testing and reference voltage adjustment. A possible solution consists of dipping the circuit housing in paraffin; however, the adjustment screw on the ten turn potentiometer would somehow have to remain accessible. Another possibility is to place the circuit in a PVC pipe plugged at both ends by a compression fitting. This would be similar to the installation procedure employed at the TUSD sites (see Appendix B). Although only one compression fitting was used to plug the top of the pipe, overwatering controllers at TUSD sites usually stayed dry as they were not placed inside the control valve box. Compression fittings at both ends may be the most economical solution.

6.4 Circuit Modification

The present design of the overwatering controller circuit uses a pulse counter to record the number of skipped irrigation cycles. This has three disadvantages.

First, to quantify water savings, it was imperative that weekly irrigation schedules at test sites were known at all times. Although close contact was maintained with test site representatives concerning plant response, an inordinate amount of time was spent each week in keeping informed of any changes to timer settings.

Second, the pulse counter coil had a very low impedance of 65 Ohms, resulting in a relatively high current draw of 150 to 200 milliamps. The remainder of the circuit draws less than 5 milliamps. Such a difference in current draw, depending on the operational mode, made balancing components in the power conversion subcircuit rather difficult and may have reduced circuit performance. A similar pulse counter with a high impedance coil could have averted this problem; however, availability of such counters was limited and none could be obtained in sufficient numbers for this study.

Third, the pulse counter is mechanical and becomes unreliable when exposed to excessive condensation. As the circuit was installed in moist environments, pulse counters had to be repaired or replaced occasionally. It is

therefore likely that the true amount of water savings reported may have been underestimated.

During the early stages of circuit development, inexpensive digital quartz clocks were intended to record actual times of irrigation cycles allowed and skipped. Such clocks have a very low current draw and have been used in opportunity-advance timers for surface irrigation studies (Jordan *et. al.*, 1991). Indeed, these clocks would have eliminated the first two disadvantages of the pulse counter; however, the former is far more susceptible to moisture damage than the latter. Hence, the decision was made to use a pulse counter rather than digital clocks.

Given the disadvantages of the pulse counter and the need to eliminate circuit exposure to moisture anyhow, it becomes worthwhile to reconsider using the digital quartz clocks. Figure 6.1 shows a possible circuit design incorporating the clock and eliminating the pulse counter. This is modeled after the opportunity-advance timer circuit of Jordan, *et. al.* (1991).

Finally, it should be noted that each irrigation station requires its own overwatering controller circuit. Should the circuit become commercialized, it may be possible to integrate a single circuit into the timer. This would eliminate the need for an overwatering controller at each station.

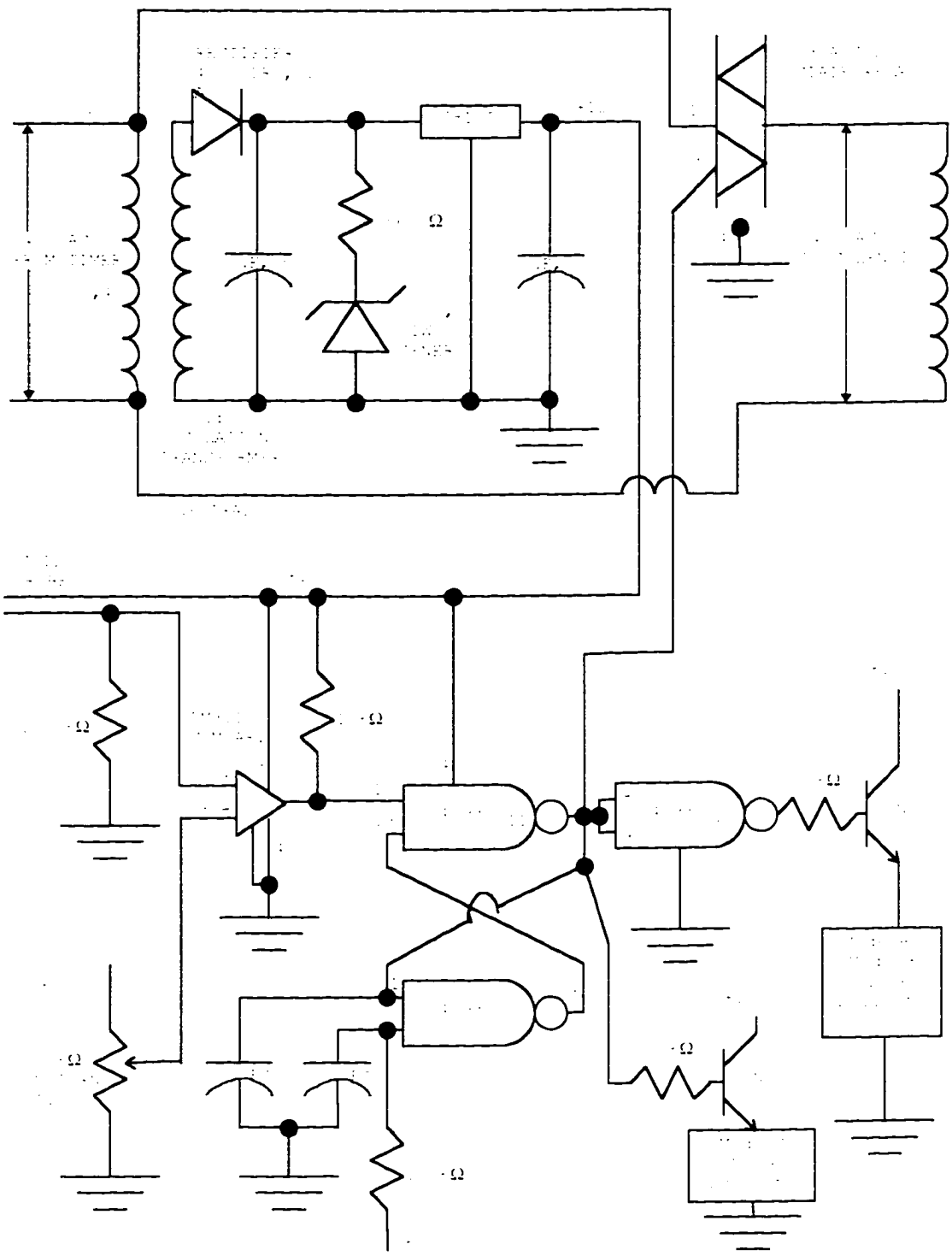

Figure 6.1:
Modified overwatering controller schematic diagram.

CHAPTER 7: CONCLUSIONS

An electronic device called the overwatering controller was developed to address water conservation and possible improvements in deficit irrigation for timer controlled landscape irrigation systems. Deficit irrigation has been found to both conserve water and benefit plants; however, this technique has been difficult to achieve as plant water requirements vary.

The overwatering controller consists of an electronic circuit and a soil probe. The soil probe senses soil moisture conditions in the plant root zone. The overwatering controller allows irrigations to take place at stations when soil moisture conditions have been depleted below a certain level. Otherwise, irrigation cycles are skipped. The soil moisture condition at which an irrigation cycle is skipped is adjustable using a reference voltage setting within the circuit.

Fifty overwatering controllers were tested on landscape irrigation systems at various locations throughout Tucson, Arizona during the summer and fall 1996 growing season. The test sites included parks, schools, homes, apartments, and the Reid Park Zoo. Test stations consisted of thirty seven sprinkler stations containing mostly Bermuda grass, five bubbler stations, and eight emitter stations containing trees and shrubs. Test results indicated that thirty five

percent of irrigation water was saved in terms of volume, and thirty percent of irrigation cycles were skipped.

Actual evaluation of deficit irrigation requires continuous measurement of soil moisture content and was cost prohibitive for this study. The overwatering controller merely senses soil moisture conditions at the beginning of an irrigation cycle. Use of the overwatering controller, however, reduced depths applied at sprinkler stations and shows promise for improving deficit irrigation.

Reference voltage adjustments were based on visual plant observations at stations where the overwatering controller was installed. These observations were compared to plants at adjacent (control) stations without the overwatering controller. Reference voltages were adjusted upward when plants showed signs of stress; upward adjustment reduced the number of irrigation cycles skipped. Similarly, reference voltages were reduced at stations where overwatering was observed.

It is recommended that the initial reference voltage be set at 9 volts at sites irrigated with potable water and 11 volts at sites irrigated with reclaimed water. The reference voltage should be adjusted as necessary.

APPENDIX A: FIVE SUB-CIRCUITS OF THE OVERWATERING CONTROLLER

Appendix A contains a detailed discussion of the design and operation of the five sub-circuits of the overwatering controller. The sub-circuits are defined as

(1) soil probe and comparitor;

(2) NAND gate flip-flop;

(3) pulse counter;

(4) solid state relay; and

(5) power converter.

A.1 Soil Probe and Comparitor

The soil probe is the component that senses soil water content which is a function of soil conductivity. The component is buried in the ground. It "tells" the circuit of the overwatering controller whether an irrigation cycle is needed based on soil conductivity. Construction, geometry, and installation methods of the soil probe are discussed in Appendix B.

The soil probe and comparitor sub-circuit are illustrated in fig. A.1. The high side of the soil probe is maintained at a potential of 12 V DC anytime the timer is energizing the station. The low side potential is a function of the distance between the soil probe copper cap contacts, as well as soil and water conductive properties present. The low side potential therefore varies according to Ohm's Law:

$$Vl = Vh - Rp * C \qquad (A.1)$$

where Vl = Low side potential

Vh = High side potential = 12 V

Rp = Effective resistance across the probe contacts

C = Current.

The low side of the soil probe is connected to a LM311 comparitor at pin 2+ and a grounded 100 KΩ resistor. The 100 KΩ resistor acts as a current sensing resistor; 100 KΩ was found to provide the largest variation in potential of the low side as the soil dries (fig A.2).

The comparitor functions as an "ON-OFF" switch, where potential is switched either on or off at 7. The potential at 3- is the "reference voltage;" this may be adjusted from 0 to 12 V by turning a screw on the ten turn potentiometer. If the low side potential at 2+ is greater than the reference voltage at 3-, then the potential at 7 is switched ON (12 V); other wise, the potential at 7 is switched OFF (0 V). Operation of the comparitor is summarized as follows:

Condition	7
(2+) > (3-)	ON
(2+) < (3-)	OFF

Depending on the reference voltage setting, potential at 7 may be either ON or OFF for a given soil moisture content. The ten turn potentiometer provides for field adjustment of the level of soil moisture depletion desired for the overwatering controller to prevent irrigations.

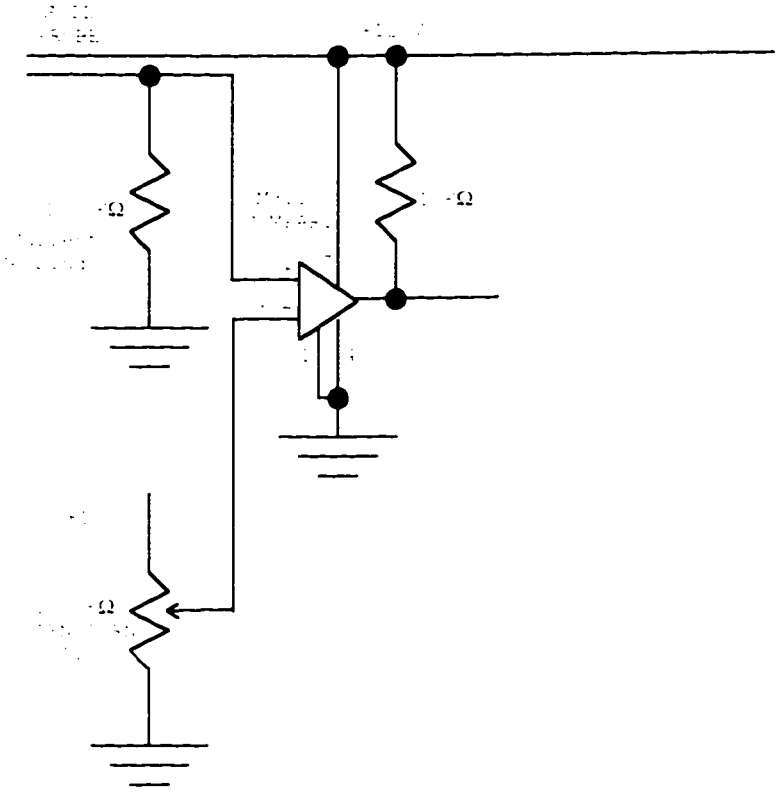

Figure A.1: Soil probe and comparitor sub-circuit.

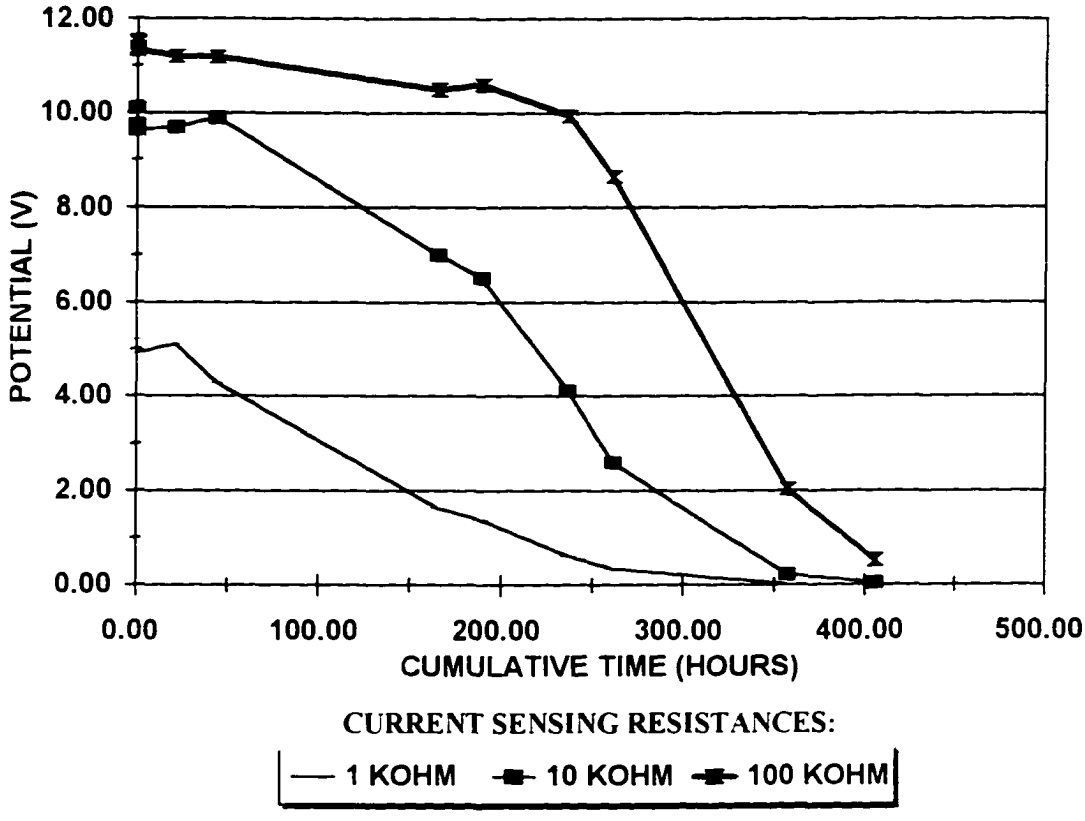

Figure A.2: Low side potential vs. time for a drying sandy loam soil for various current sensing resistances.

A.2 NAND Gate Flip-Flop

A single NAND gate operates in the following manner (fig. A.3), where "L" designates low potential (0 V), and "H" designates high potential (12 V).

1	2	3
L	L	H
L	H	H
H	L	H
H	H	L

Figure A.3: NAND Gate.

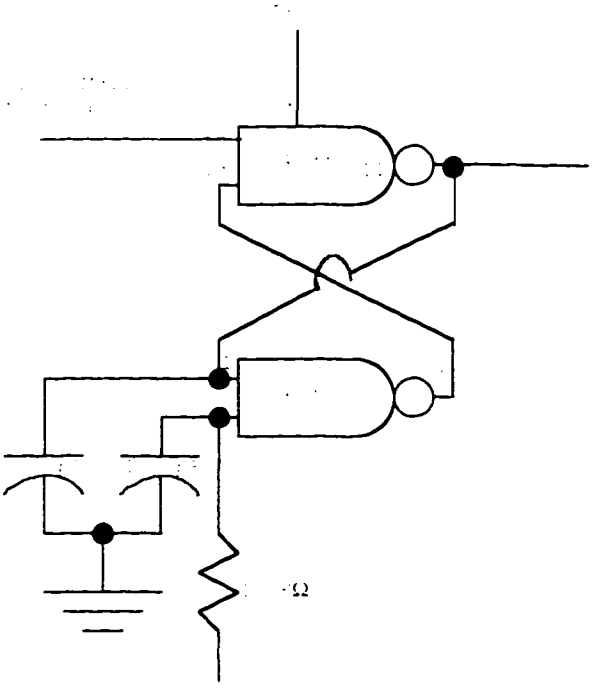

Figure A.4: Flip flop sub-circuit.

The operation of the LM311 comparitor is limited to whether the soil is wet or dry, and the soil at the probe will become wet shortly after the beginning of an irrigation. Since we would like the overwatering controller not to interrupt an irrigation that has already begun, we need two NAND gates in a flip flop configuration (fig. A.4).

A CD4093 is an integrated circuit (IC) chip containing four NANDs; two of these are used for the flip-flop. Terminal 12 of the flip-flop is connected to terminal 7 of the LM311 comparitor; hence, the LM311 is the input to the flip-flop. Terminal 11 of the flip-flop is connected to a solid state relay that closes the timer-to-solenoid circuit. Thus, if 11 is high, the solid state relay closes the circuit to the solenoid, and watering begins. Operation of the flip-flop is summarized as follows in terms of operational modes of the overwatering controller (Table A.1).

Table A.1: Logic of Flip Flop and Results

MODE	Soil	Time	Flip Flop Terminal 12	1,11	2	3,13	Result
A	dry	Instant of start up	L	L	L	H	
A	dry	Shortly after start up	L	H	H	L	Irr.
B	wet	Minutes after start up	H	H	H	L	Irr.
C	wet	Instant of start up	H	L	L	H	
C	wet	Shortly after start up	H	L	H	H	No Irr.

When modes switch from A to B when the wetting front reaches the soil probe, note that terminals 1 and 11 remained high even though terminal 12 went from low to high.

The two 100 pF capacitors function as energy storage devices to prevent miss-firing of the flip flop at the instant of start up. At this instant, they ensure that 1,11 and 2 are low, so that 3,13 is high. As 2 becomes high shortly after start up, 3,13 switches to low only if 12 is low (MODE A), and 1,11 switch to high. However, 3,13 remain high if 12 starts high (MODE C), and 1,11 remain low so that the irrigation is prevented. 1,11 will switch to high only if 12 is low at start up, and the irrigation proceeds.

The 1 KΩ resistor at 12 and the 10 KΩ resistor at 2 provide pull up.

A.3 Pulse Counter

The pulse counter records the number of times an irrigation is prevented (MODE C). With the timer irrigation schedule known (frequency and duration of irrigations) at a station, the pulse counter allows the percentage of water savings to be calculated. If the flowrate to all water applicators in the station is known, the actual quantity of water saved may be estimated based on the number of pulse counts recorded.

The pulse counter used was obtained from Marlin P. Jones and Associates, Inc.[1] of Lake Park, Florida, model IVO #F112.60. This is a 12 V DC, non-resettable, low impedance unit with a 65 Ω coil. The pulse counter sub-circuit is shown in Figure A.5.

A third NAND gate is used from the CD4093. Terminals 8 and 9 are tied to terminal 11 of the flip-flop. In MODES A and B, 8 and 9 are high, so 10 is low. In MODE C, 8 and 9 are low, and 10 is high.

An NPN TIP 121 transistor is used to switch the pulse counter on by closing its circuit to ground; this occurs when 10 is high.

The low impedance of the pulse counter results in a relatively high current draw (150 mA) compared to other

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[1] Mention of trade names is solely for the benefit of the reader and does not imply endorsement by the author or the University of Arizona.

components. To limit current draw while still providing enough current for the pulse counter to operate, a 24 Ω, 2 Watt resistor is used.

Finally, a 400 V diode is used to prevent a spike from coil inductance when the pulse counter switches on or off.

A.4 Solid State Relay

A CRYDOM D2W203F solid state relay is used to close the timer-to-solenoid 24 V AC circuit when the overwatering controller is in MODE A or B. The relay is rated at 3 A at 220 V AC, with a control range of 3 to 32 V DC. Terminal 11 of the flip-flop (CD4093) is connected to the solid state relay control terminal 3 (fig. A.6).

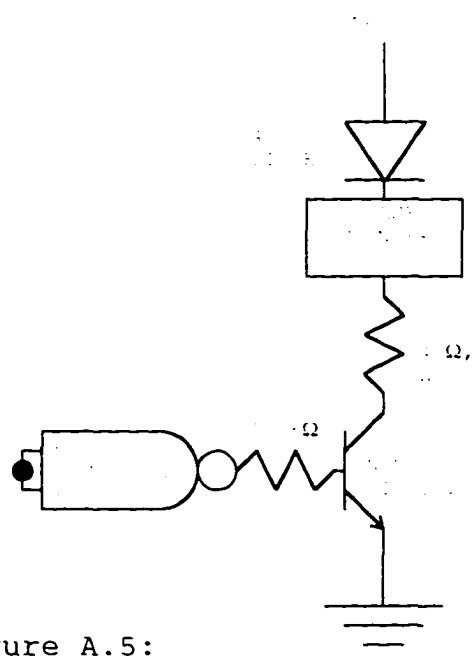


Figure A.5:
Pulse counter sub-circuit.

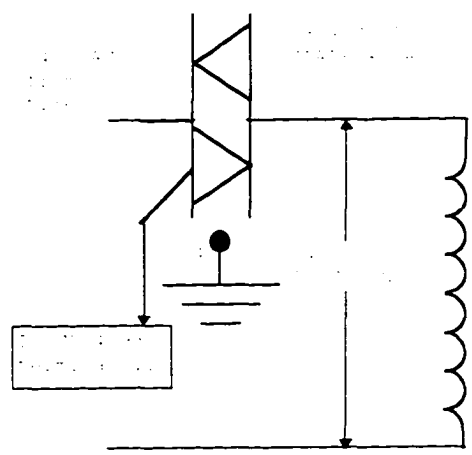


Figure A.6:
Solid state relay.

A.5 Power Conversion

The components within the overwatering controller are generally rated to operate at 12 V DC. Since these components need to operate only when the timer energizes a station, the controller may be passive and use the power supplied by the timer. The timer power supply must then be converted from 24 V AC to 12 V DC.

The power conversion circuit consists of a 1:1 isolation transformer, 400 VPRV 1 A half wave rectifier, two 220 uF 50 V capacitors, 560 Ω resistor, 27 V 1 W Zener diode, and a 7812T 12 V voltage regulator (fig. A.7).

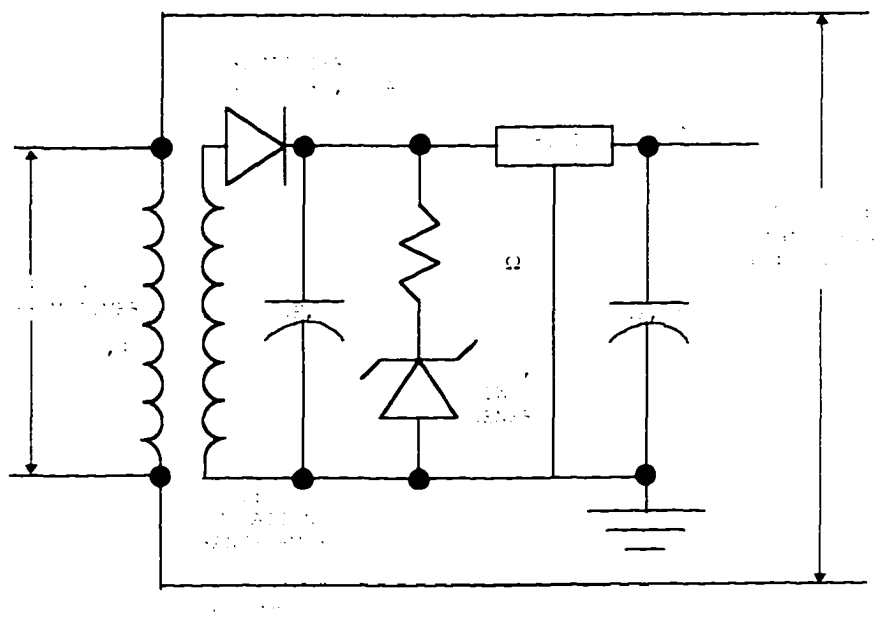
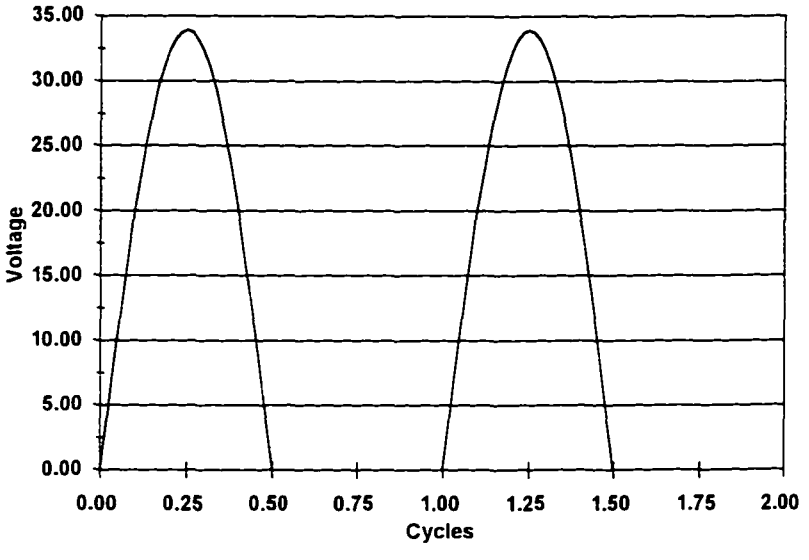


Figure A.7: Power conversion sub-circuit.

(a)



(b)

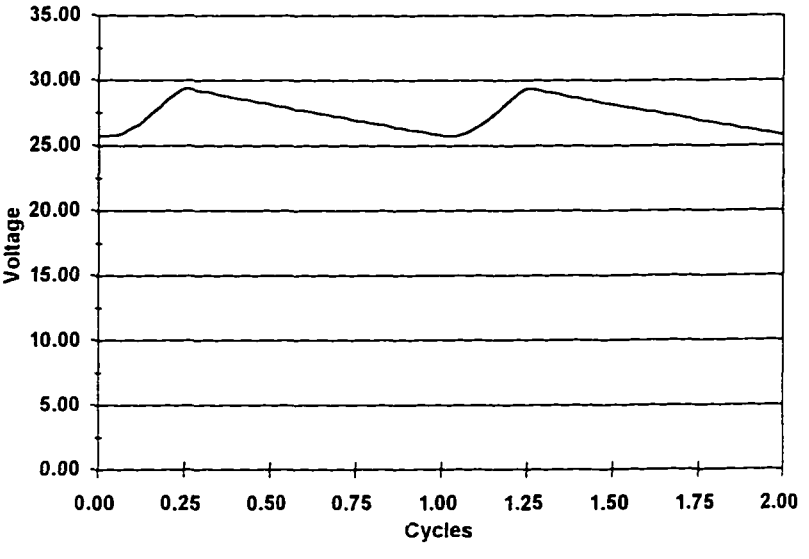


Figure A.8: (a) Half wave (rectified) 24 V AC sinusoid;
(b) result of (a) with capacitor.

(c)

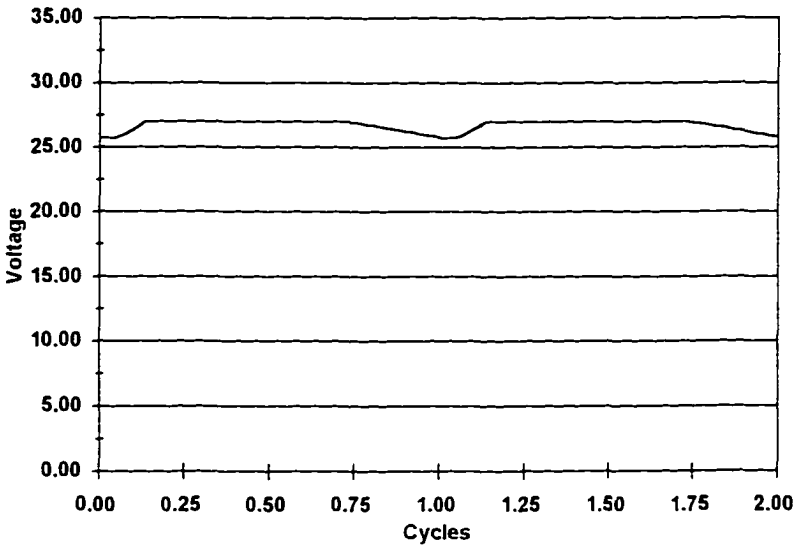


Figure A.8: (c) Result of (b) with 27 V Zener diode.

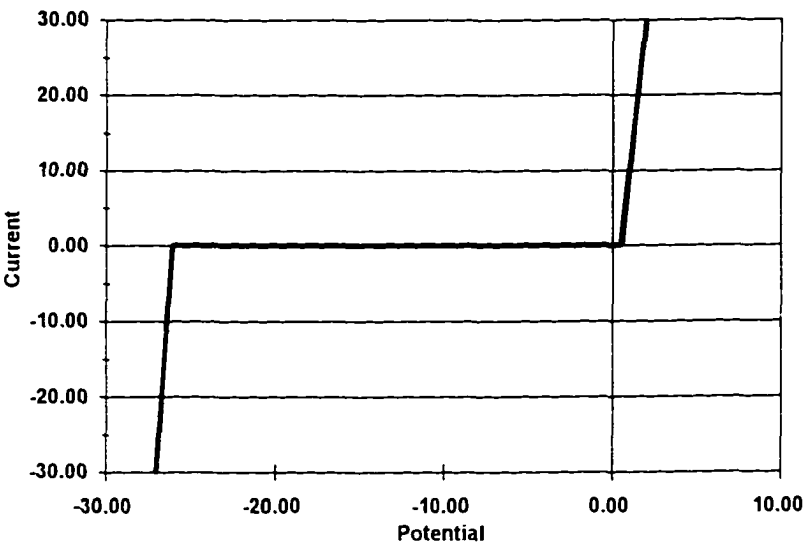


Figure A.9:
Current vs. potential shows function of 27 V Zener diode.

With 24 V AC coming in from the timer, the 1:1 isolation transformer (its purpose will be explained shortly) provides 24 V AC to the half wave rectifier. A half wave rectifier was chosen over a full wave bridge type rectifier to remain within the power handling capacity of the 7812T voltage regulator. The capacitor immediately following the rectifier smoothes the resulting half sinusoid (fig A.8).

The 560 Ω resistor and 27 V 1 W Zener diode reduce the peak voltage coming out of the rectifier as this peak voltage may exceed the maximum input voltage rating (35 V) of the 7812T voltage regulator. Also, reducing the peak voltage removes ripples from the curve (fig. A.8c), resulting in a truer DC voltage.

The voltage reported for an AC power source (24 V in this case) is the root mean square (RMS) of the AC sinusoid. The peak voltage is larger. With 24 V AC at 60 cycles per second (Hertz, Hz), the instantaneous voltage as a function of time is

$$V(t) = V_p * \sin(120*\pi*t) \qquad (A.2)$$

where V_p is the peak voltage and t is in seconds. The RMS voltage is found by taking the square of V(t), integrating over a cycle, and taking the square root of the result:

$$V_{rms} = V_p \sqrt{\int \sin^2[2*\pi*t/(1/60)]\, dt} = \frac{V_p}{\sqrt{2}} \qquad (A.3)$$

Solving for V_p, we have $V_{rms} * \sqrt{2} = 24 * \sqrt{2} = 34$ V. This is almost at the maximum voltage rating of 35 V for the 7812T. This voltage should be reduced slightly by using a Zener diode.

A Zener diode can be used to limit potential on the negative (band) side when it becomes saturated. Its operation is illustrated in figure A.9. As the potential (abcisca) becomes more negative, current (ordinate) is suddenly allowed to flow at the saturation point. With the Zener turned so that the negative (band) side is opposite of ground potential on the overwatering controller, it sees potential above ground potential as negative.

The 27 V 1 W Zener diode then maintains a 27 V potential at the side opposite of the overwatering controller ground potential; however, potential at the 7812T regulator can be increased to 30 V by placing a 560 Ω resistor before the Zener. Thirty volts is safely below the 35 V maximum rating of the 7812T regulator, but provides adequate power to ensure operation of the pulse counter.

Finally, the 7812T regulator reduces voltage to 12 V for the remainder of the overwatering controller circuit.

Also, the second 220 uF capacitor was placed on the 12 V side of the power sub-circuit to dampen spikes caused by coil inductance of the isolation transformer.

An earlier design of the overwatering controller lacked the 1:1 isolation transformer. It was discovered that the transformer was necessary for proper soil probe operation sometime after a number of controllers had been installed at test sites. Recall that the soil probe high side is maintained at 12 V DC with respect to neutral. It was postulated that the soil probe low side will be less than 12 V *but above neutral potential* depending on soil moisture present. In order for the controller to operate in MODE C, the low side potential of the soil probe *must exceed* the reference voltage set by the ten turn potentiometer. With the timer neutral of the TCLIS at ground potential, however, stray voltage present in the ground reduced the soil probe low side potential to or slightly above neutral potential. The soil probe low side was in effect *grounded*. Consequently, the overwatering controller could never operate in MODE C and skip irrigation cycles, no matter how much moisture was present in the soil.

The isolation transformer then isolates the overwatering controller circuit from the timer-to-solenoid circuit. The neutral potential of the former differs with respect to the neutral potential of the latter. The

isolation transformer used was obtained from Herback and Rademan Company of Bristol, Pennsylvania, model TM92XFR2000.

A.6 Overall circuit design

The complete overwatering controller circuit schematic is repeated here again for convenience and clarity (fig. A.10); Figure A.11 is a process flow diagram of the circuit operation.

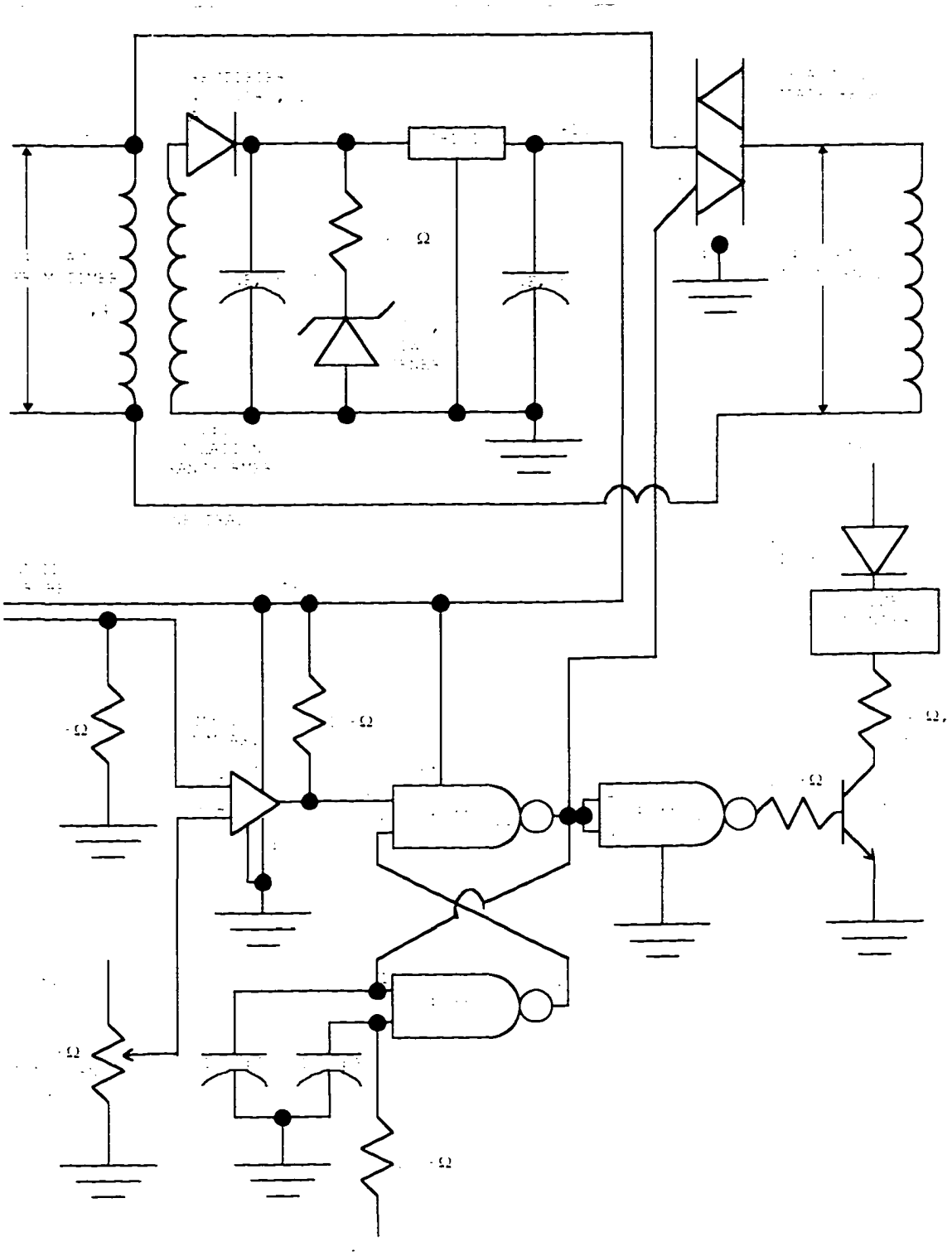


Figure A.10: Overwatering controller schematic diagram.

Figure A.11: Overwatering controller process flow diagram.

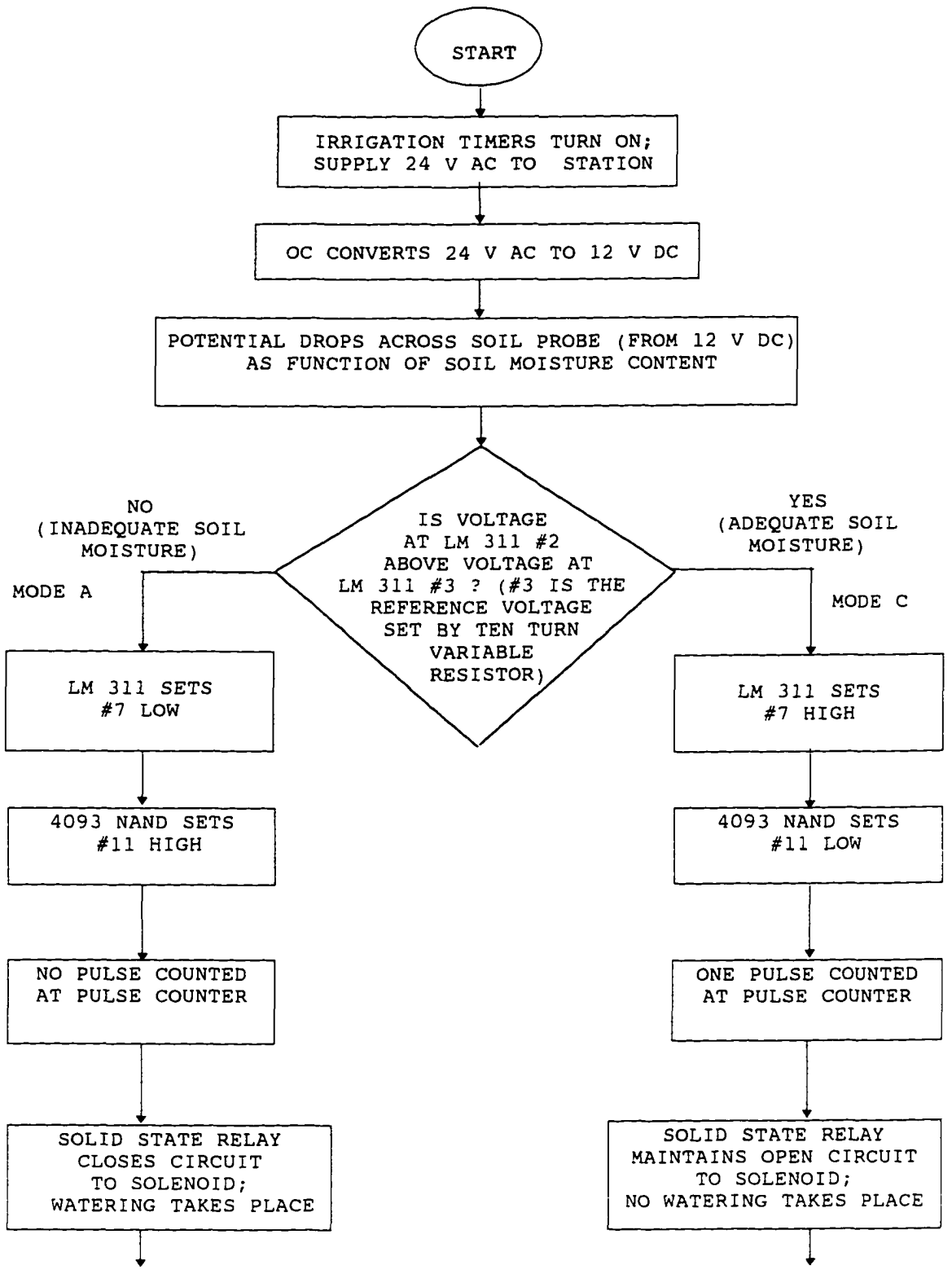
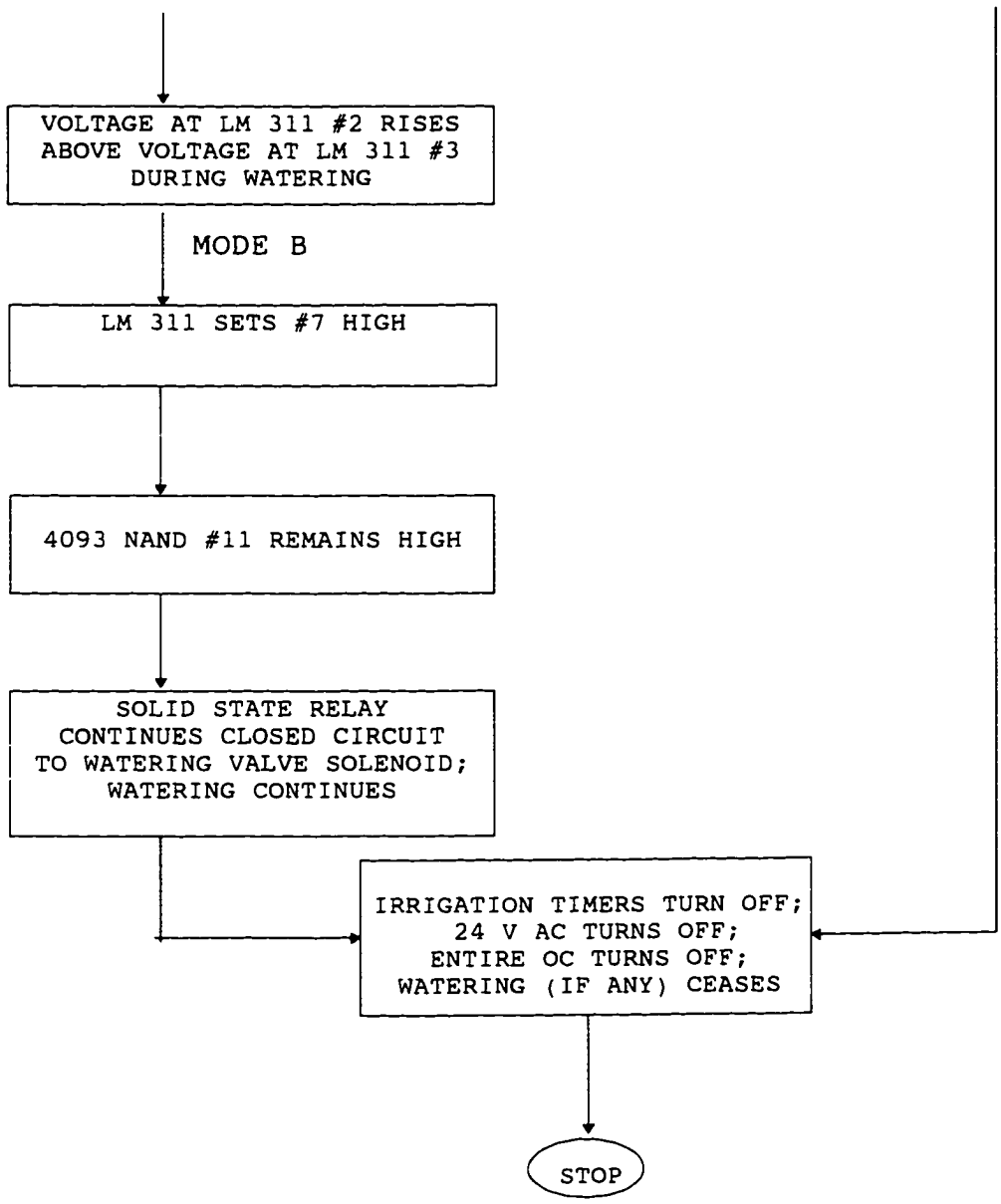


Figure A.11 *(continued)*
Overwatering controller process flow diagram.



APPENDIX B:

OVERWATERING CONTROLLER FABRICATION AND INSTALLATION

B.1 Circuit and Circuit Housings

The circuit of the overwatering controller was built by soldering individual electronic components to a printed circuit board (fig. B.1). The printed circuit board presented here reflects minor changes to the leads necessary when the isolation transformer was later incorporated to the circuit. Seventy nine circuit boards were produced by Circuit Engineering and Development[1] , Tucson, Arizona. With fifty overwatering controller prototypes field tested, this allowed twenty nine extra circuit boards so that prototypes could be changed in the field if repairs were needed. The printed circuit board contains all components except for the isolation transformer (added later), pulse counter, and the soil probe.

The printed circuit board and pulse counter were housed in a Carlon type FSE standard outdoor receptacle box (part no. E980DF). The front of the receptacle box was covered with a Carlon GFI receptacle cover (part no. E980GFC). The circuit board was placed on the front of the receptacle box with the cover anchored over it. Slots were milled and holes were drilled in the receptacle box to accommodate the pulse counter and a terminal block (fig. B.2). The terminal

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[1] Mention of trade names is solely for the benefit of the reader and does not imply endorsement by the author or the University of Arizona.

block provided a means to quickly connect or disconnect the overwatering controller to the irrigation system wiring (fig. B.3).

The six terminals of the terminal block are numbered ascending toward the pulse counter. The printed circuit board diagram (fig. B.1) shows connections to the inside of the terminal block (opposite external screws) as "TB1" through "TB6."

The receptacle box and the isolation transformer were installed in the irrigation control valve box of an irrigation station. Both the receptacle box and transformer were housed in a Sterilite six quart (14-1/2"L x 8"W x 4-5/8" H) clear storage box with a snap top lid (part no. 1752). The lid was sealed to the box with silicon caulk to keep moisture out. In cases where the Sterilite box was too large to fit in the irrigation station control valve box, the transformer was sealed in a thirteen ounce coffee can and the receptacle box was sealed in a plastic freezer bag.

SCALE: 0.10" = 0.05"

DRILL LARGE HOLES 0.050" DIA.
DRILL SMALL HOLES 0.035" DIA.

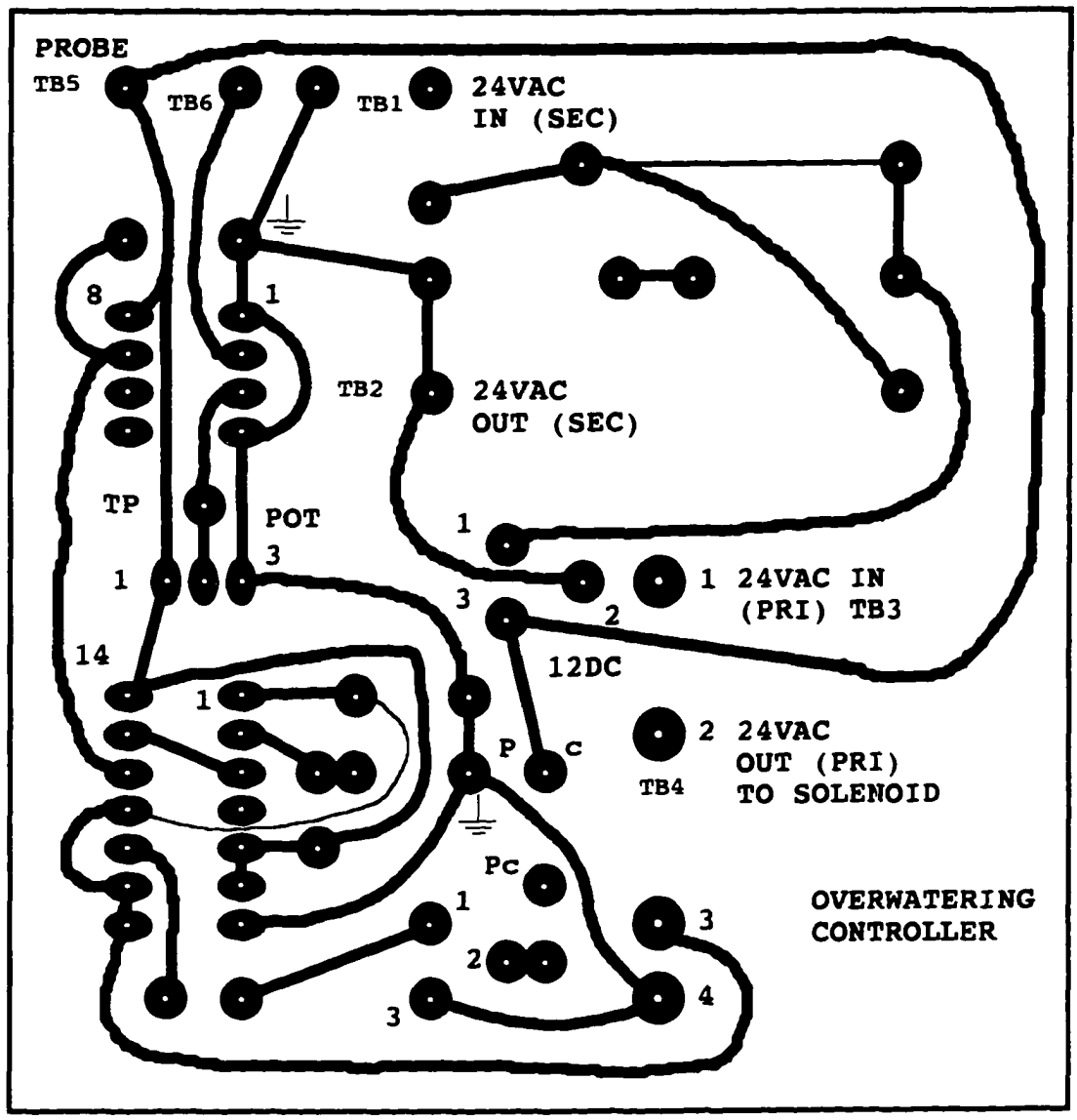

Figure B.1: Circuit board wiring diagram. Scale is 2X actual size.

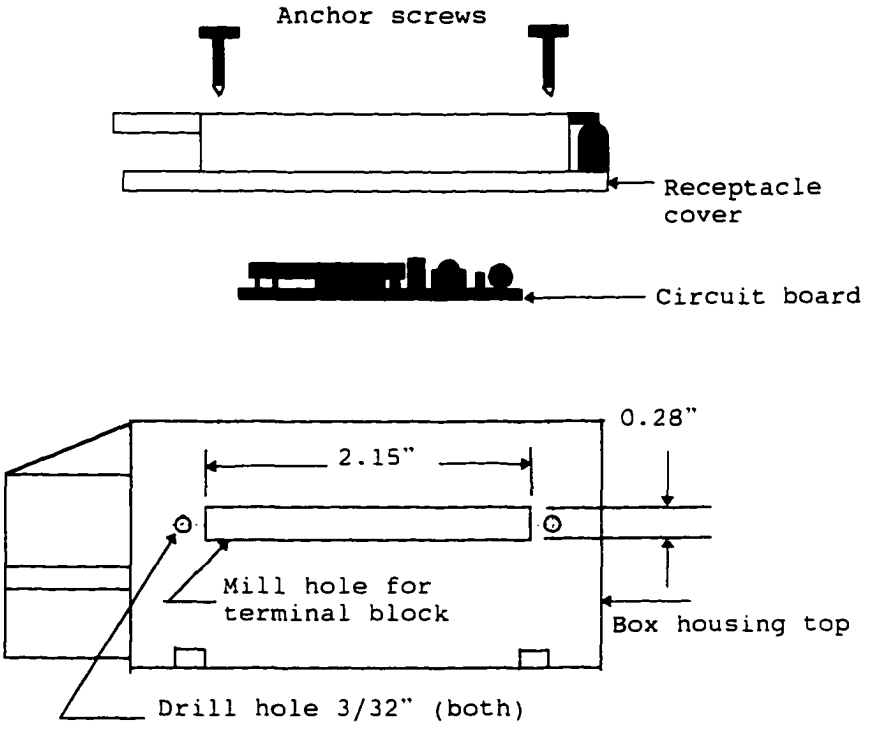

Figure B.2:
Holes to be milled and drilled in Carlon receptacle box for terminal block and pulse counter (not to scale).

B.2 Installation Wiring

Figure B.3 illustrates the external installation wiring of the overwatering controller.

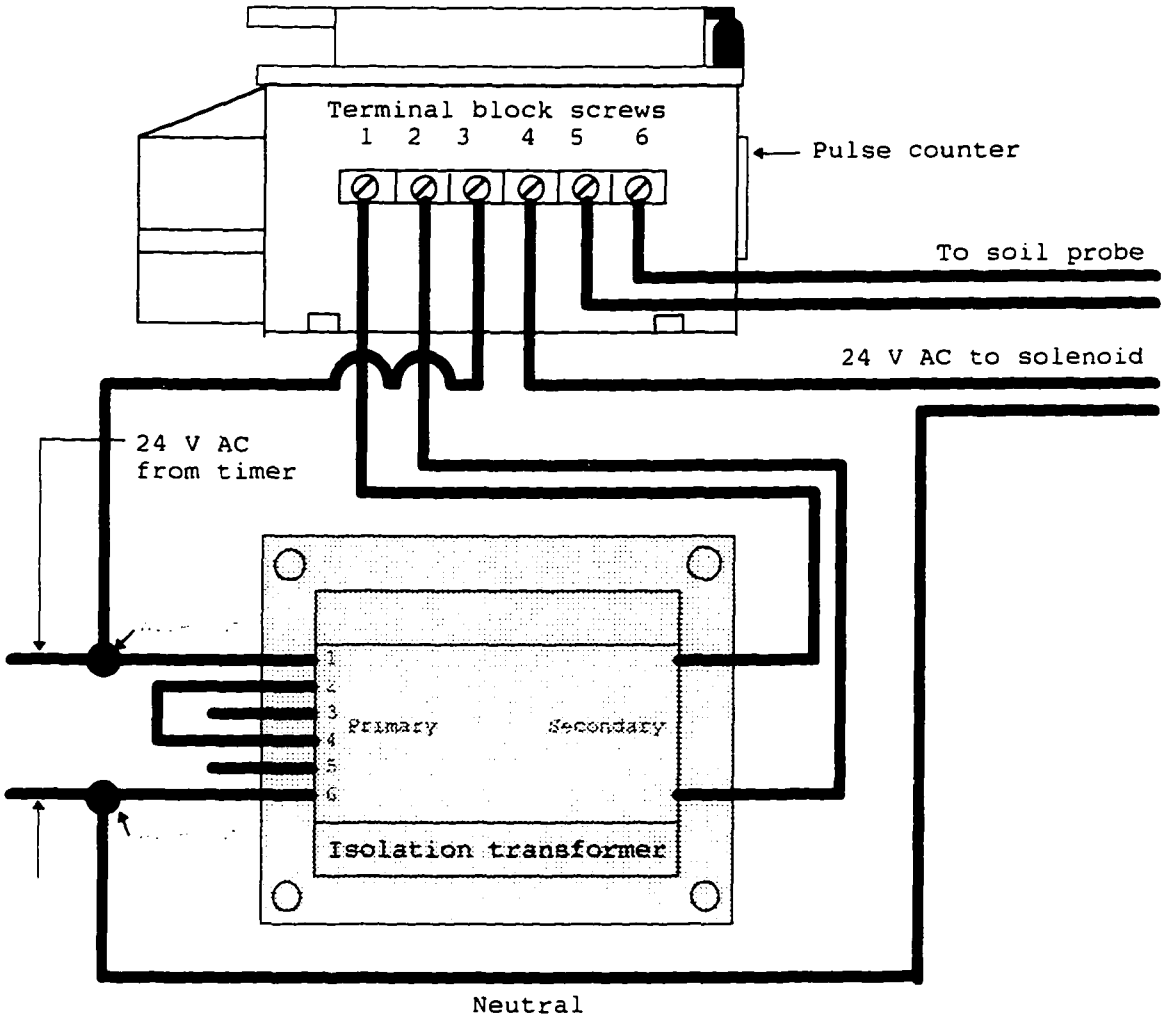

Figure B.3. Overwatering controller installation wiring.

B.3 Soil Probe

B.3.1 Construction and Geometry

The soil probe consists of two contacts placed several inches below the ground surface, near the bottom of the plant root zone (fig. 3.2). The contacts are placed horizontally with respect to each other. The contacts consist of two half inch copper cap sweat fittings. The caps are mounted on each end of a half inch CPVC 4120 ASTM D2846 pipe that is two inches in length. Two 18 gauge wires are soldered to the copper caps and connect the soil probe to the remainder of the electronic circuit.

The soil probe construction and geometry are based on the findings of Cairo (1991). Copper caps were recommended over other means of contact such as metal rods to lessen to effects of soil hysteresis. Soil hysteresis is the differing relationships between soil moisture content and matric potential, depending on whether the soil is drying or becoming wet (fig. B.4). A discussion of the causes of hysteresis may be found in Hillel (1982).

B.3.2 Soil Probe Installation

Station distribution uniformities (DU) of installation sites have not been determined as of this writing. With DU unknown, there was concern of placing the soil probe in station areas that are continually overwatered. This would result in most of the irrigation cycles being skipped. If the station had poor DU, however, vegetation in areas already being underwatered would become severely stressed.

By the same token, if the soil probe was placed in underwatered areas, the overwatering controller would be effective only during periods of precipitation when soil wetting would be more uniform in the station area. To be conservative, soil probe placement was chosen in favor of the latter case. Soil probes were placed as far from sprinklers or other applicators as practical, assuming this is where the least amount of water is applied.

With a point in the station area chosen, the soil probe was buried at depths of four to six inches. This was usually the depth of grass root zones. With high evaporation rates characteristic of Tucson, it was assumed that soil moisture depletion would progress down from the soil surface. It was further assumed that this would result in irrigations occurring only when minimal soil moisture depletion extended throughout the root zone. With soil

moisture depleted beyond the wilting point near the surface, deeper root growth will be encouraged to obtain moisture. It is postulated that deficit irrigation may be achieved in this way.

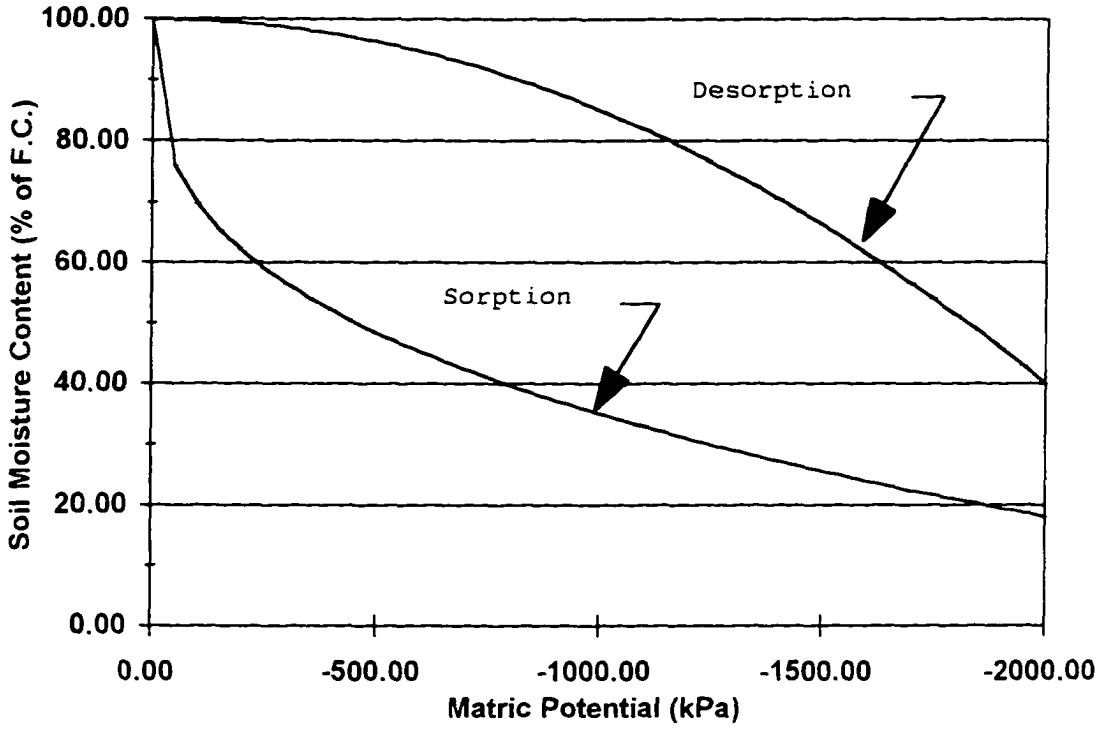

Figure B.4:
Soil hysteresis. Soil moisture content (as a percentage of field capacity) vs. matric potential for a typical loam, depending on whether the soil is drying (desorption) or becoming wet (sorption).

B.4 Special Installation Procedure for TUSD Sites

Installation of the three Tucson Unified School District (TUSD) elementary school sites presented a special installation problem for the overwatering controllers. Normally overwatering controllers are installed in the irrigation station control valve boxes. The lids to these control valve boxes at TUSD sites, however, are buried several inches to prevent tampering by school children. Overwatering controllers must also be inaccessible to children, yet easily accessible for the Grantee.

Installation to meet this criteria was achieved by burying vertically a 12 inch long by 6 inch diameter PVC pipe adjacent to the control valve boxes (fig. B.5). The PVC pipe houses the overwatering controllers. The top of the PVC pipe is flush with the ground surface. A 6 inch plug insert that is tightened by a compression nut protects the top of the PVC pipe; the plug will in turn be protected by a slide-on PVC cap.

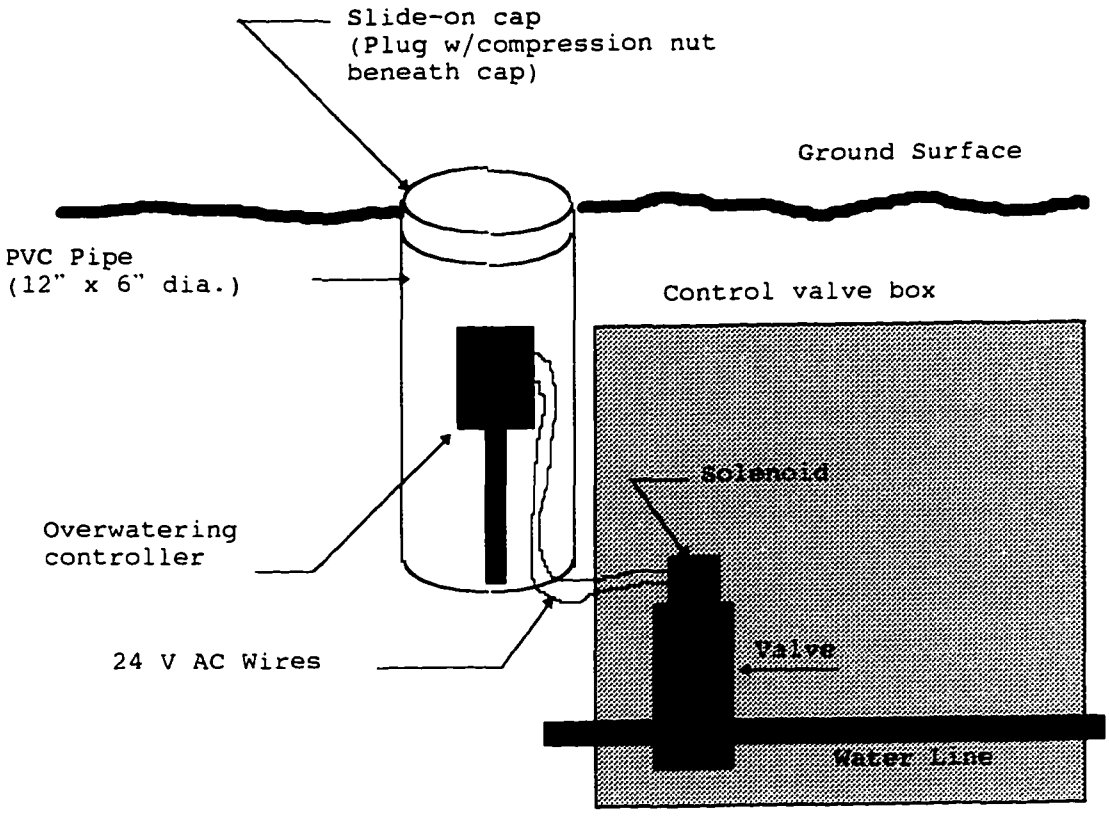

Figure B.5: Installation at TUSD sites.

APPENDIX C:

PROCEDURES FOR CIRCUIT TESTING

AND REFERENCE VOLTAGE ADJUSTMENT

A special apparatus was designed and built to test the overwatering controller circuit and to adjust the reference voltage (fig. C.1). The test apparatus is portable and may be used in the field at installation sites. The apparatus consists of a box made of plywood with a hinged and latching lid. The box contains a battery power supply and a tool compartment. The lid has a clipboard for field data collection sheets, two voltmeters, five test circuit switches, and a test solenoid mounted on it. Overall dimensions of the test box are 18"L x 12"W x 9"H.

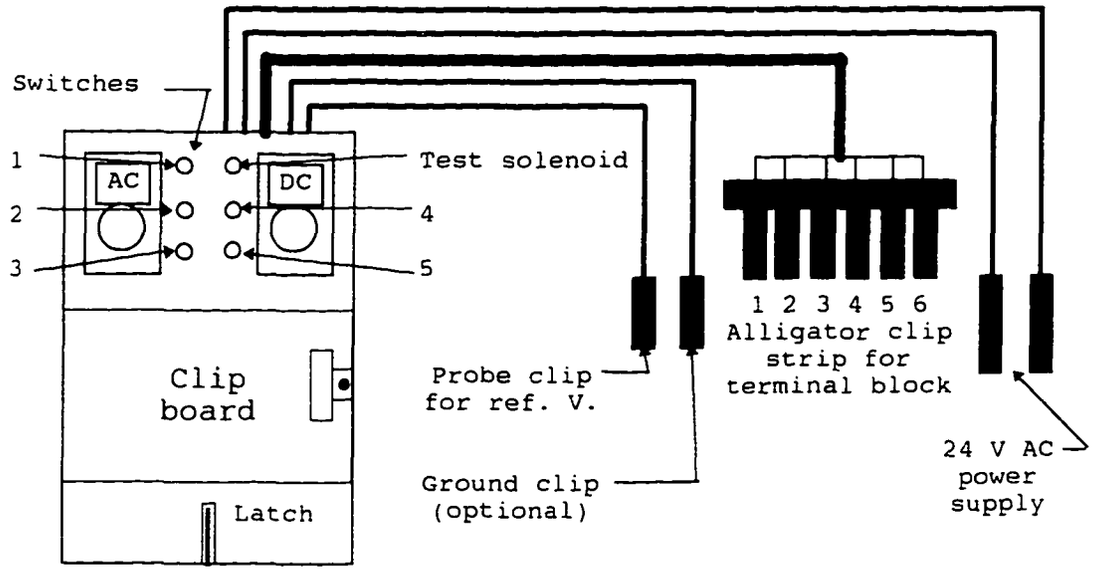

Figure C.1: Overwatering controller testing apparatus (top).

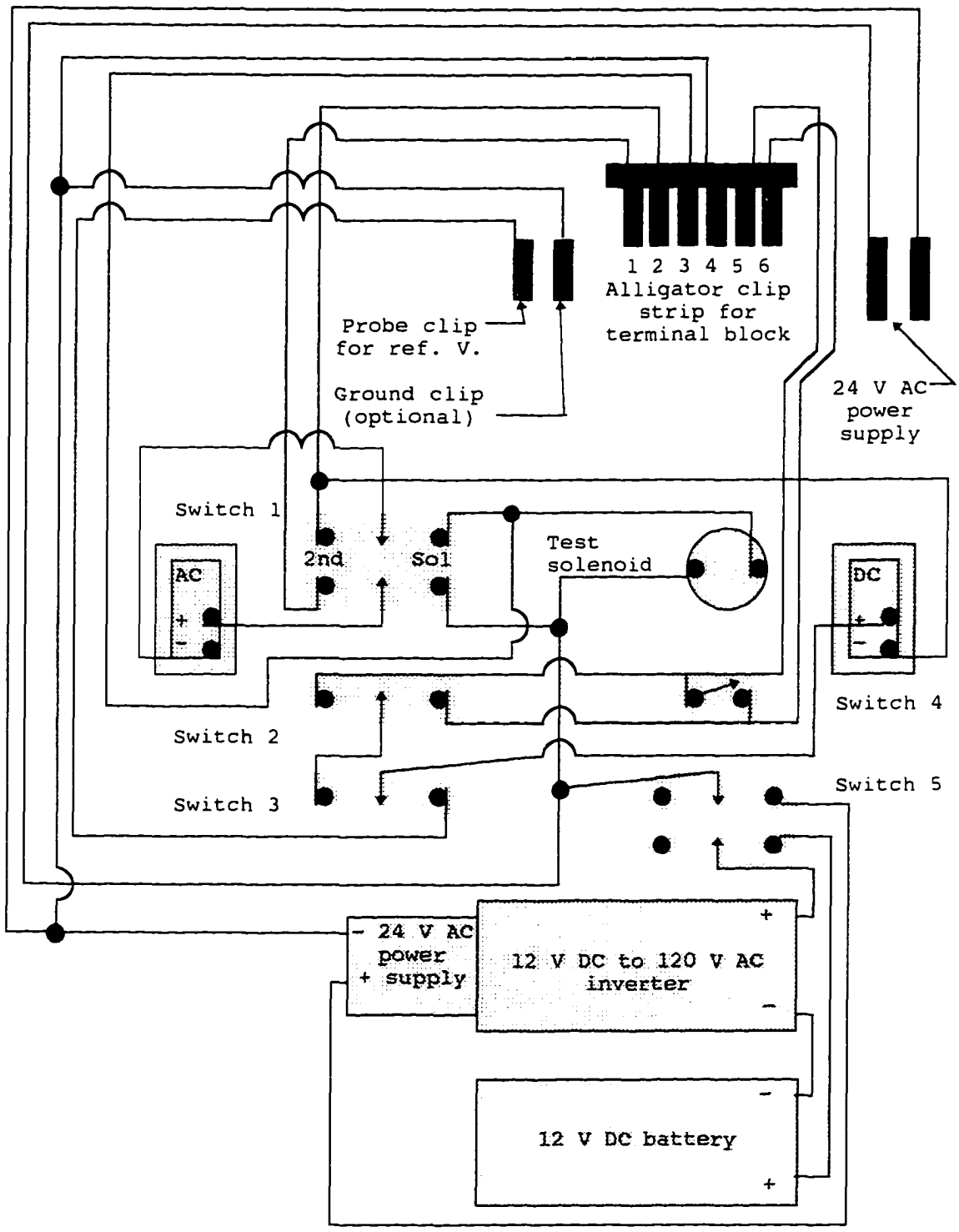

Figure C.2: Test circuit wiring diagram.

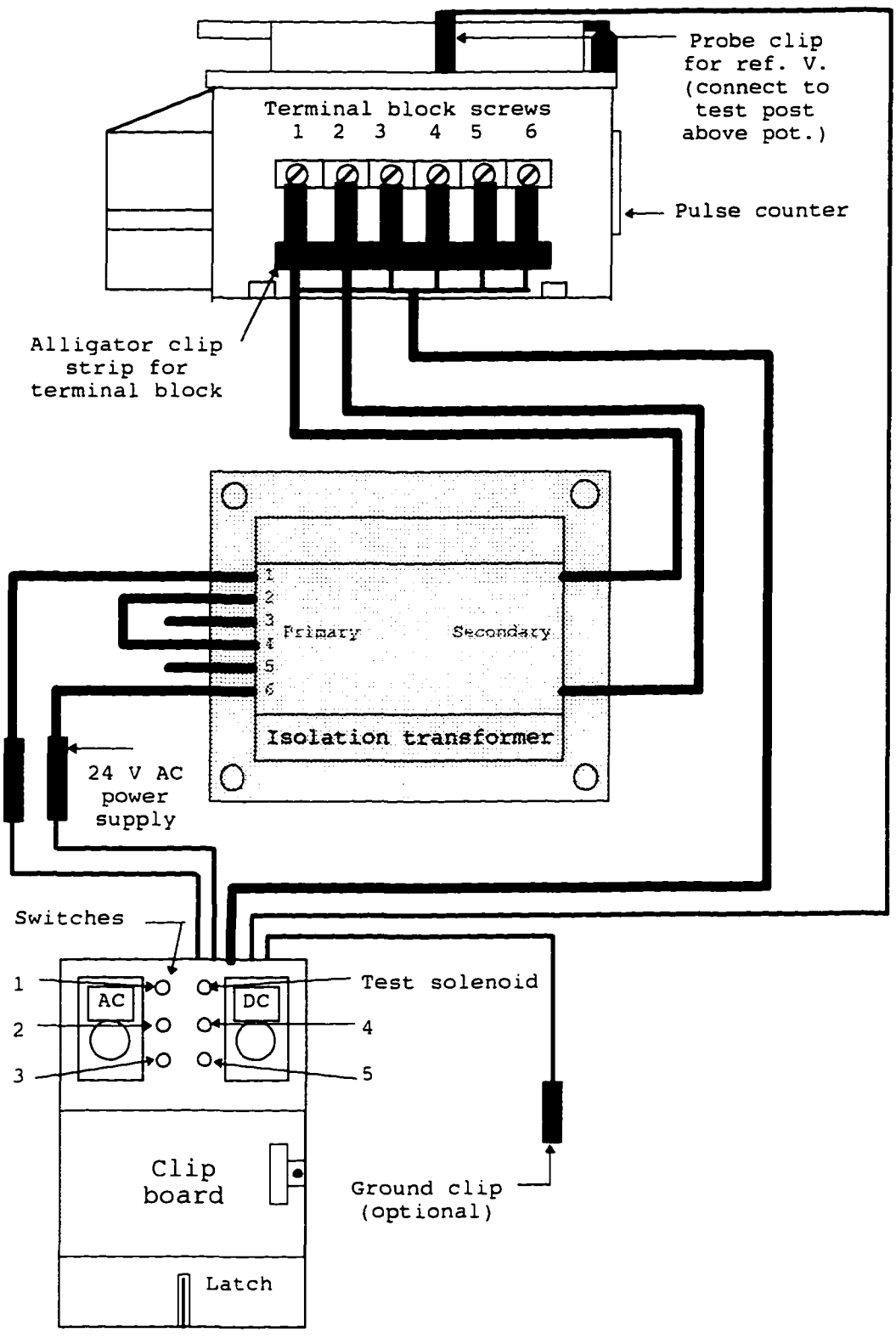

Figure C.3: Test circuit set up procedure.

C.1 Test Circuit

The test circuit is powered by a Douglas-Guardian model DG 12-7 battery. The battery is a sealed, rechargeable, deep cycle, 12 V DC, 7.0 AH unit. The 12 V DC from the battery is converted to 120 V AC with a Tripp Lite Lap Power inverter, model PV 125. The 120 V AC is then stepped down with a DVE 24 V AC Power Supply, model DV 2412A. The DVE Power Supply is rated at 120 V AC, 60 Hz, 35 W for input, and 24 V AC, 1.2 A for output.

The test circuit uses two multimeters, five switches, and a irrigation system valve solenoid (fig. C.2). The switches allow for various voltage test points to be read and the three operational modes (MODE A, MODE B, MODE C) to be tested without reconnecting any wires or multimeters. The functions of the five switches are summarized as follows:

Switch 1 (DPDT)

Left: Isolation transformer secondary coil voltage. Read at multimeters-meter 1.

Center: Off

Right: Valve solenoid (AC) voltage. Read at multimeter 1.

Switch 2 (SPDT)

Left: Soil probe high side (DC) voltage.
Read at multimeter 2.

Center: OFF

Right: Soil probe low side (DC) voltage.
Read at multimeter 2.

Switch 3 (SPDT)

Left: Enables Switch 2.

Right: Disables Switch 2.
Reads reference (DC) voltage at multimeter 2.

Switch 4 (SPST)

Left: OFF. Prevents terminal 6 of the terminal block (soil probe low side) from gaining any potential. Simulates dry soil conditions.
Allows testing of MODE A.

Right: Shorts terminals 5 and 6 of the terminal block (soil probe terminals). With terminals 5 and 6 shorted, soil probe high side voltage equals low side voltage (12 V DC). Saturated soil conditions at the soil probe are therefore simulated. Allows testing of MODE B and MODE C.

Switch 5 (DPDT)

Left: OFF

Center: OFF

Right: POWER ON

C.2 Test Set Up

Figure C.3 illustrates the set up procedure for testing the overwatering controller. Prior to set up, check connections to ensure they are free from excessive rust or corrosion.

C.3 Testing Procedure

Mode A

1) Initial switch settings:
Switch 1 (Left); Switch 2 (Right); Switch 3 (Left);
Switch 4 (Left); Switch 5 (Center).

2) Turn Switch 5 (Power) ON (Right).

3) Desired results:
Solenoid becomes energized. Multimeter 1 measures at least 24 V AC. Multimeter 2 measures at least 12 V DC. If these are obtained, skip to (5).

4) Diagnostics:
If any desired results are not obtained, check switch settings and connections. Return to (1).
If pulse counter counts while Switch 2 is set left, the LM311 comparitor and/or 4093 flip flop may be frozen in MODE C. Replace LM311 and/or 4093 IC chip(s) and return to (1).

5) Turn Switch 3 to right. Turn Switch 1 to right.

6) Desired results:
Multimeter 1 measures at least 24 V AC.
Multimeter 2 measures reference voltage, usually 9 to 10 V DC. This can range from 0 to 12 DC by turning the potentiometer screw adjustment on the circuit board.

7) Diagnostics:
Be certain that the red probe clip is attached to the reference voltage post (just above potentiometer) on the circuit board.

8) Turn Switch 3 back to left. Turn Switch 2 to right.
Leave Switch 5 (Power) ON (Right).

9) Desired results:
Solenoid remains ON. Multimeter 2 measures 0 V DC.

Mode B

10) Turn Switch 4 ON (Right).

11) Desired results:
Solenoid remains energized.
Multimeter 2 measures 12 V DC. If so, skip to (13).

12) Diagnostics:
If Multimeter 2 is less that about 12 V DC, check terminal block connections. If solenoid goes off, LM311 or 4093 may be defective. Replace IC chip(s) and return to (1).

13) Turn Switch 5 (Power) OFF (Left).

Mode C

15) Turn Switch 5 (Power) ON (Right).

16) Desired results:
Solenoid DOES NOT come on. Pulse counter counts.
Multimeter 2 measures 12 V DC.
If so, testing is complete.

17) Diagnostics:
If solenoid comes on, does Multimeter 2 measure 12 V DC (soil probe low side)? If not, check connections.
If so, LM311 or 4093 IC chips may be frozen in MODE A.
Replace chip(s) and return to (1).

C.4 Measurement of *In Situ* Soil Probe Potential and Reference Voltage

Soil probe potentials may be measured in the field by using the set up of Figure C.3, but with the soil probe wires connected to terminals 5 and 6 of the terminal block. Initial switch settings remain the same as (1) in the Testing Procedure. Simply turn the power ON. Soil probe high side and low side potentials are measured by turning Switch 2 left and right, respectively, on Multimeter 2. Note that if the low side potential exceeds the reference voltage, the overwatering controller should start in MODE C.

The reference voltage may be adjusted in the field by simply turning Switch 3 to the right and turning the potentiometer screw until the desired reference voltage is measured on Multimeter 2. Be certain that the red probe clip is secured to the reference voltage post (just above the potentiometer) on the circuit board.

CAUTION: In performing field tests or readings, be certain the irrigation system solenoid valve wires are NOT contacting terminals 4 or 5 on the terminal block. Otherwise, sprinklers will come on if the overwatering controller is tested in MODE A.

APPENDIX D: SITE TECHNICAL INFORMATION

Appendix D contains technical information of sites where overwatering controllers are installed. This information includes the names and addresses of agencies participating in this study, names and addresses of sites, descriptions and locations of test and control stations, vegetation, and estimations of station flow rates and precipitation rates. Table D.1 lists each site.

With a few exceptions, station flow rates were estimated using specifications from manufacturer's catalogs. These catalogs include the Hunter 1996-97 Irrigation Products Catalog, Rainbird Landscape Irrigation Products 1993-1994 Catalog and Specifications Manual, and the Toro Irrigation Products 1996-1997 Catalog.[1] In cases where manufacturer's specifications were not available, station flow rates were estimated from the agency or site representatives' knowledge of the irrigation system. Line pressures were assumed at sixty pounds per square inch unless otherwise noted.

Station precipitation rates were estimated by

$$PR = 96.3 \times Q / A \qquad (D.1)$$

where PR = Precipitation rate (inches per hour)
96.3 = unit conversion factor
Q = flow rate to area (gallons per minute)
A = area (square feet).

[1] Mention of trade names is solely for the benefit of the reader and does not imply endorsement by the author or the University of Arizona.

Table D.1: Overwatering controller test sites.

Agency	Site	No. Of Controllers Installed
Mike Kostrzewski	Private Residence	2
Ed Louy	Private Residence	1
Mark Mullaney	Private Residence	1
Los Palmas Apartments		4
Pima County Community Resources Zone 1: Northwest (contact: Mark Nuno)	Arthur Pack Regional Park	4
	Meadowbrook Park	2
	Richardson Park	2
Pima County Community Resources Zone 2: Southwest (contact: Christopher Bartos)	Cardinal Park	1
	Lawrence Park	1
	Mission Ridge Park	2
Tucson Parks and Recreation Department (contact: Les McMullen)	Reid Park Zoo	6
City of Tucson	Sunset Park (City Hall)	7
Tucson Parks and Recreation Department (contact: James Martinez)	Aviation Bikeway at 16th St. & Highland (near Murphy's Overpass)	2
Tucson Unified School District (contact: Linda S. Wright or Jim Ward)	Myers-Ganoung Elementary	5
	Hudlow Elementary	5
	Ft. Lowell Elementary	5
	Total	**= 50**

Agency	Pima County Community Resources (Zone 1, Northwest) 1204 West Silverlake Road Tucson, Arizona 85713-2799		
Site (Potable water)	Arthur Pack Regional Park 9101 N. Thornydale Rd. Tucson, AZ		
Station Vegetation	3 Bermuda Grass Ballfield #6, NE corner of park, left outfield, North fence		5 Bermuda Grass Ballfield #6, NE corner of park, left infield, North & West fences
Test or Control?	test		test
Water Applicators	Rainbird Sprinklers R70, #22, green (1/2 arc)	(full arc)	Rainbird Sprinklers R70, #22, green (1/2 arc)
Applicators per sta.	2	3	6
GPM per applicator	21.3	21.3	21.3
Total Station GPM	106.5		127.8
Applic. spacing (ft)	61 Triangular		61 Triangular
Precip. rate (in/hr)	0.81		0.81

Site (Potable water)	Arthur Pack Regional Park 9101 N. Thornydale Rd. Tucson, AZ		
Station Vegetation	9 Bermuda Grass Ballfield #6, NE corner of park, right infield, West fence		13 Bermuda Grass Ballfield #6, NE corner of park, right outfield, South fence
Test or Control?	test		test
Water Applicators	Rainbird Sprinklers R70, #13, red (1/2 arc)	(full arc)	Rainbird Sprinklers R70, #13, red (1/4 arc)
Applicators per sta.	5	1	6
GPM per applicator	10.5	10.5	10.5
Total Station GPM	63.0		63.0
Applic. spacing (ft)	51 Square		51 Square
Precip. rate (in/hr)	0.78		0.78
Notes: Ballfield #6 slopes from NE to SW; very sandy soil but high runoff. Areas 1-4 south of wash; areas 5-10 north of wash. Areas 1-5 irrigated with pumped ground water; areas 6-10 irrigated with city potable water.			

Agency	City of Tucson Parks and Recreation 900 South Randolph Way Tucson, AZ 85716			
Site (Potable water)	Aviation Bikeway At 16th Street and Highland Avenue (near Murphy's Overpass) Tucson, AZ			
Station Vegetation	13T Trees	14S Shrubs	15T Trees	16S Shrubs
Test or Control?	Test	Test	Control	Control
Water Applicators	Rainbird Xerigation	Rainbird Xerigation	Rainbird Xerigation	Rainbird Xerigation
Applicators per Station	168 (42 trees, 4 emitters per tree)	132 (132 shrubs 1 emitter per shrub)	236 (59 trees, 4 emitters per tree)	79 (79 shrubs 1 emitter per shrub)
GPH per Applicator	1	1	1	1
Total Station GPH	168	132	236	79
Total Station GPM	2.8	2.2	3.9	1.3

Agency	Pima County Community Resources (Zone 2, Southwest) 1204 West Silverlake Road Tucson, Arizona 85713-2799	
Site (Potable water)	Cardinal Park 6925 S. Cardinal Ave. Tucson, AZ	
Station Vegetation	13 Bermuda Grass North side along path	14 Bermuda Grass NE end along path
Test or Control?	Test	Control
Water Applicators	Rainbird Sprinklers 50 psi 27/37 (1); 21/31 (3) (full circle) #14 Nozzle	Rainbird Sprinklers 50 psi 27/37 (1); 21/31 (4) (full circle) #14 Nozzle
Applicators per sta.	4	5
GPM per applicator	9.4	9.4
Total Station GPM	37.6	47
Applic. spacing (ft)	46 Square	46 Square
Precip. rate (in/hr)	0.43	0.43

Agency	Tucson Unified School District Facilities Management 530 S. Norris Tucson, AZ 85719	
Site (Reclaimed water)	Ft. Lowell Elementary 5151 E. Pima Tucson, AZ 85712	
Station Vegetation	C-8 Bermuda grass N of E parking lot (West-central area)	C-10 Bermuda grass 2nd station N. of East parking lot (West-central area)
Test or Control?	Test	Test
Water Applicators	Sprinklers Hunter I-40	Sprinklers Hunter I-40
Applicators per sta.	7	9
GPM per applicator	8	8
Total Station GPM	56	72
Applic. spacing (ft)	60 Square	60 Square
Precip. rate (in/hr)	0.21	0.21

Site (Reclaimed water)	Ft. Lowell Elementary 5151 E. Pima Tucson, AZ 85712	
Station Vegetation	C-12 Bermuda grass N of building, W & S of basketball courts	C-14 Bermuda grass E fence & N of basketball courts
Test or Control?	Test	Test
Water Applicators	Sprinklers Hunter I-40	Sprinklers Hunter I-40
Applicators per sta.	9	9
GPM per applicator	8	8
Total Station GPM	72	72
Applic. spacing (ft)	56 Square	56 Square
Precip. rate (in/hr)	0.24	0.24
Note: Two irrigation flow meters located SE corner of school.		

Agency	Tucson Unified School District Facilities Management 530 S. Norris Tucson, AZ 85719	
Site (Reclaimed water)	Ft. Lowell Elementary 5151 E. Pima Tucson, AZ 85712	
Station Vegetation	C-17 Bermuda grass N, 3rd station from North fence	C-15 Bermuda grass N, 1st station from North fence
Test or Control?	Test	Control
Water Applicators	Sprinklers Hunter I-40	Sprinklers Hunter I-40
Applicators per sta.	9	9
GPM per applicator	8	8
Total Station GPM	72	72
Applic. spacing (ft)	56 Square	56 Square
Precip. rate (in/hr)	0.24	0.24

Site (Reclaimed water)	Ft. Lowell Elementary 5151 E. Pima Tucson, AZ 85712	
Station Vegetation	C-16 Bermuda grass N, 2nd station from North fence	C-9 Bermuda grass West fence
Test or Control?	Control	Control
Water Applicators	Sprinklers Hunter I-40	Sprinklers Hunter I-40
Applicators per sta.	9	7
GPM per applicator	8	8
Total Station GPM	72	56
Applic. spacing (ft)	56 Square	56 Square
Precip. rate (in/hr)	0.24	0.24
Note: Two irrigation flow meters located SE corner of school.		

Agency	Tucson Unified School District Facilities Management 530 S. Norris Tucson, AZ 85719	
Site (Potable water)	Hudlow Elementary 502 N. Caribe Av Tucson, AZ 85710	
Station Vegetation	1 Trees NW Parking Lot	3 Hedges North Courtyard.
Test or Control?	Test	Control
Water Applicators	Bubblers Rainbird 140-A	Bubblers Rainbird 140-A
Applicators per sta.	43	59
GPM per applicator	1	1
Total Station GPM	43	59

Site (Potable water)	Hudlow Elementary 502 N. Caribe Av Tucson, AZ 85710	
Station Vegetation	7 Bermuda grass S. central yard next to building on hill	8 Bermuda grass S. central yard next to building on hill
Test or Control?	Test	Control
Water Applicators	Sprinklers Hunter I-40	Sprinklers Hunter I-40
Applicators per sta.	6	6
GPM per applicator	8	8
Total Station GPM	48	48
Applic. spacing (ft)	55 Square	55 Square
Precip. rate (in/hr)	0.25	0.25
Notes: Main irrigation meter is located SW corner of grounds; booster pump for sprinklers located by meter.		

Agency	Tucson Unified School District Facilities Management 530 S. Norris Tucson, AZ 85719	
Site (Potable water)	Hudlow Elementary 502 N. Caribe Av Tucson, AZ 85710	
Station Vegetation	13 Bermuda grass East Yard	11 Bermuda grass SE of building
Test or Control?	Test	Control
Water Applicators	Hunter Sprinklers I-40	Hunter Sprinklers I-40
Applicators per sta.	6	7
GPM per applicator	8	8
Total Station GPM	48	56
Applic. spacing (ft)	55 Square	55 Square
Precip. rate (in/hr)	0.25	0.25

Site (Potable water)	Hudlow Elementary 502 N. Caribe Av Tucson, AZ 85710	
Station Vegetation	14 Bermuda grass East Yard	16 Trees East fence
Test or Control?	Test	Test
Water Applicators	Hunter Sprinklers I-40	Bubblers Rainbird 140-A
Applicators per sta.	6	14
GPM per applicator	8	1
Total Station GPM	48	14
Applic. spacing (ft)	55 Square	N/A
Precip. rate (in/hr)	0.25	N/A
Notes: Main irrigation meter is located SW corner of grounds; booster pump for sprinklers located by meter.		

Agency	Mike Kostrzewski 12958 N. Whitlock Canyon Dr. Oro Valley, AZ 85737			
Site (Potable water)	Private residence			
Station Vegetation	1 Annual flowers	2 Garden vegetables	3 Shrubs	4 Shrubs
Test or Control?	Test	Test	Control	Control
Water Applicators	Emitters	Emitters	Emitters	Emitters
Applicators per Station	97	37		
GPH per Applicator	4	4		
Total Station GPH	388	148		
Total Station GPM	6.5	2.5		

Agency	Ed Louy 199 W. Geeseman Springs Dr. Oro Valley, AZ 85737
Site (Potable water)	Private residence
Vegetation	Bermuda or Rye Grass
Test or Control?	Test
Water Applicators	Sprinklers Orbit Spray STD Pop-up (12' rad) 90 degree
Applicators per sta.	6
GPM per applicator	0.67
Total Station GPM	4.0
Applic. spacing (ft)	24 x 16
Precip. rate (in/hr)	1

Agency	Mark & Leanne Mullaney 12946 N. Whitlock Canyon Dr. Oro Valley, AZ 85737	
Site (Potable water)	Private residence	
Vegetation	Bermuda or Rye Grass	
Test or Control?	Test	
Water Applicators	Sprinklers, Toro 570-10 deg. 10-SSQ-PC (13' rad) 90 degree	10-SSH-PC (13' rad) 180 degree
Applicators per sta.	4	1
GPM per applicator	0.7	1.4
Total Station GPM	4.2	
Applic. spacing (ft)	13 Triangular	
Precip. rate (in/hr)	1.6	

Agency	Pima County Community Resources (Zone 2, Southwest) 1204 West Silverlake Road Tucson, Arizona 85713-2799	
Site (Potable water)	Lawrence Park 6777 S. Mark Rd. Tucson, AZ	
Station Vegetation	3 Bermuda grass Along West fence by parking (left control box)	4 Bermuda grass Outfield east of Station 3 (2nd left cntrl box)
Test or Control?	test	control
Water Applicators	Rainbird Sprinklers 27/37 (1/2 cir.) # 10 Nozzles	Rainbird Sprinklers 27/37 (full circle) # 10 Nozzles
Applicators per sta.	8	12
GPM per applicator	5.4	5.4
Total Station GPM	43.2	64.8
Applic. spacing (ft)	42 Triangular	42 Triangular
Precip. rate (in/hr)	0.47	0.23

Agency	Pima County Community Resources (Zone 1, Northwest) 1204 West Silverlake Road Tucson, Arizona 85713-2799	
Site (Reclaimed water)	Meadowbrook Park 2635 W. Sandbrooke Lane Tucson, AZ	
Station Vegetation	1 Bermuda Grass North side near slope	16 Bermuda Grass East side near slope
Test or Control?	Test	Test
Water Applicators	Rainbird Sprinklers 51AP (double, full cir.) 3/16" 14x11	Rainbird Sprinklers 51AP (double, full cir.) 3/16" 14x11
Applicators per sta.	3	4
GPM per applicator	18.0	18.0
Total Station GPM	54.0	72.0
Applic. spacing (ft)	59 Triangular	59 Triangular
Precip. rate (in/hr)	0.4	0.4

Agency	Pima County Community Resources (Zone 2, Southwest) 1204 West Silverlake Road Tucson, Arizona 85713-2799
Site (Potable water)	Mission Ridge Park 3300 W. Tucker Rd. Tucson, AZ
Station Vegetation	9 Bermuda Grass West side, 3rd station from school fence
Test or Control?	Test
Water Applicators	Rainbird Sprinklers 50 psi 27/37 (half circle) #9 Nozzle
Applicators per sta.	7
GPM per applicator	3.9
Total Station GPM	27.3
Applic. spacing (ft)	41 Triangular
Precip. rate (in/hr)	0.36

Site (Potable water)	Mission Ridge Park 3300 W. Tucker Rd. Tucson, AZ	
Station Vegetation	10 Bermuda Grass West side, 2nd station from school fence	11 Bermuda Grass West side, along school fence
Test or Control?	Test	control
Water Applicators	Rainbird Sprinklers 50 psi	Rainbird Sprinklers 50 psi
	51AP (full circle)	51AP (full circle)
	13 x 9 Nozzles	13 x 9 Nozzles
Applicators per sta.	4	4
GPM per applicator	14.5	14.5
Total Station GPM	58.0	58.0
Applic. spacing (ft)	55 Triangular	55 Triangular
Precip. rate (in/hr)	0.36	0.36

Agency	Tucson Unified School District Facilities Management 530 S. Norris Tucson, AZ 85719	
Site (Reclaimed water)	Myers-Ganoung Elementary 5000 E. Andrew Tucson, AZ 85711	
Station Vegetation	13 Bermuda grass S. side of building	Bermuda grass S. side of building next to timer shed
Test or Control?	Test	Control
Water Applicators	Sprinklers Hunter I-40	Sprinklers Hunter I-40
Applicators per sta.	3	5
GPM per applicator	8	8
Total Station GPM	24	40
Applic. spacing (ft)	30 Square	36.25 Square
Precip. rate (in/hr)	0.86	0.59

Site (Reclaimed water)	Myers-Ganoung Elementary 5000 E. Andrew Tucson, AZ 85711	
Station Vegetation	14 Bermuda grass SE Side of building sprinklers against S building wall	Bermuda grass S Side of building sprinklers against timer shed
Test or Control?	Test	Control
Water Applicators	Sprinklers Hunter I-40	Sprinklers Hunter I-40
Applicators per sta.	4	4
GPM per applicator	8	8
Total Station GPM	32	32
Applic. spacing (ft)	36.25 Square	36.25 Square
Precip. rate (in/hr)	0.59	0.59
Note: Irrigation flow meters located SW corner of school.		

Agency	Tucson Unified School District Facilities Management 530 S. Norris Tucson, AZ 85719	
Site (Reclaimed water)	Myers-Ganoung Elementary 5000 E. Andrew Tucson, AZ 85711	
Station Vegetation	1 Bermuda grass East Fence Sprinklers along east fence	 Bermuda grass East fence Sprinklers along south side of basketball court
Test or Control?	Test	Control
Water Applicators	Sprinklers Hunter I-40	Sprinklers Hunter I-40
Applicators per sta.	5	4
GPM per applicator	8	8
Total Station GPM	40	32
Applic. spacing (ft)	36.25 Square	40 x 30
Precip. rate (in/hr)	0.59	0.64

Site (Reclaimed water)	Myers-Ganoung Elementary 5000 E. Andrew Tucson, AZ 85711	
Station Vegetation	2 Bermuda grass Sprinklers along N. (3) & W. (1) side of Basketball court	5 Bermuda grass E-SE fence Sprinklers around paved area
Test or Control?	Test	Test
Water Applicators	Sprinklers Hunter I-40	Sprinklers Hunter I-40
Applicators per sta.	4	5
GPM per applicator	8	8
Total Station GPM	32	40
Applic. spacing (ft)	36.25 Square	15 x 17.5
Precip. rate (in/hr)	0.78	2.45
Note: Irrigation flow meters located SW corner of school.		

Agency	Las Palmas Apartments 6901 E. Broadway Tucson, AZ 85710		
Site (Potable water)	Las Palmas Apartments 6901 E. Broadway Tucson, AZ 85710		
Station Vegetation	2 Bermuda or Rye Grass Front area by main office		
Test or Control?	Test		
Water Applicators	Toro Sprinklers (50 PSI) 540P 90 deg.	540P 180 deg.	570 Series 180 deg. 12 H
Applicators per sta.	5	4	2
GPM per applicator	0.63	1.55	1.55
Total Station GPM	12.45		
Precip. rate (in/hr)	1.49 (average)		

Agency	Las Palmas Apartments 6901 E. Broadway Tucson, AZ 85710	
Site (Potable water)	Las Palmas Apartments 6901 E. Broadway Tucson, AZ 85710	
Station Vegetation	2 SE patch by Building C, Bermuda or Rye Grass SE patch by Building C, NW side of apts.	
Test or Control?	Test	
Water Applicators	Toro Sprinklers (50 PSI) 570 Series 90 deg. 12-Q	570 Series 180 deg. 12-H
Applicators per sta.	6	10
GPM per applicator	0.63	1.55
Total Station GPM	19.28	
Precip. rate (in/hr)	1.5 (average)	

Agency	Las Palmas Apartments 6901 E. Broadway Tucson, AZ 85710					
Site (Potable water)	Las Palmas Apartments 6901 E. Broadway Tucson, AZ 85710					
Station	1					
Vegetation	Bermuda or Rye Grass East of pool, both sides of fence.					
Test / Cntl?	Test					
Water Applicators	Toro Sprinklers (50 PSI) 540P 90 deg. 10' rad.	540P 90 deg. 12' rad.	540P 90 deg. 15' rad.	540P 180 deg. 8' rad.	540P 180 deg. 19' rad.	540P 2/3 arc 15' rad.
Applicators per Station	5	1	1	2	1	1
GPM per appl	0.6	0.63	1.23	0.63	2.14	2.84
Total GPM	11.1					
Prec. rate	1.6 (in/hr, average)					

Agency	Las Palmas Apartments 6901 E. Broadway Tucson, AZ 85710				
Site (Potable water)	Las Palmas Apartments 6901 E. Broadway Tucson, AZ 85710				
Station	5				
Vegetation	Bermuda or Rye Grass East of pool, South of Building G.				
Test / Cntl?	Test				
Water Applicators	Toro Sprinklers (50 PSI) 540P 90 deg. 10' rad.	540P 180 deg. 10' rad.	540P 2/3 arc 10' rad.	540P 360 deg. 10' rad.	570 360 deg. 10' rad.
Applicators per Station	1	3	1	2	1
GPM per appl	0.6	0.99	1.19	1.85	1.85
Total GPM	10.31				
Prec. rate	1.47 (in/hr, average)				

Agency	Pima County Community Resources (Zone 1, Northwest) 1204 West Silverlake Road Tucson, Arizona 85713-2799			
Site (Reclaimed water)	Richardson Park 3500 W. Green Tree Dr. Tucson, AZ			
Station Vegetation	4 Bermuda Grass Parallel to West Fence		5 Bermuda Grass Parallel to West Fence	
Test or Control?	Test		Test	
Water Applicators	Rainbird Sprinklers 27-37 (1/2 cir.) # 14 (2)	21-31 (full cir.) 3/16 (1) 13/64 (3)	Rainbird Sprinklers 27-37 (1/2 cir.) # 14 (1)	21-31 (full cir.) 3/16 (1) 13/64 (4)
Applicators per sta.	2	1 3	1	1 4
GPM per applicator	10.4	8.12 9.56	10.4	8.12 9.56
Total Station GPM	57.6		56.8	
Applic. spacing (ft)	46 Square		46 Square	
Precip. rate (in/hr)	0.45 (average)		0.45 (average)	

Agency	City of Tucson (Tucson Parks and Recreation Department) 900 S. Randolph Way Tucson, AZ 85716		
Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701		
Station Vegetation	S2 Buffalo Grass (E & NE) 1st control box from E		
Test or Control?	Control		
Water Applicators	Rainbird Sprayers, SAM PRS 1804 12Q	12H	10F
arc	1/4	1/2	full
Applicators per Station	6 (2 E; 4 NE)	5 (4 E; 1 NE)	1 (1 NE)
GPM per applicator	1	2	4
Total Station GPM	20		
Prec. rate (in/hr)	2		

Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701			
Station Vegetation	S1 Buffalo Grass (SE) 2nd control box from E			
Test or Control?	Test			
Water Applicators	Rainbird Sprayers, SAM PRS 1804 12Q	12T	12H	10F
arc	1/4	1/3	1/2	full
Applicators per Station	2	2	4	1
GPM per applicator	1	1.33	2	4
Total Station GPM	16.66			
Prec. rate (in/hr)	2			
Note: Site has mainline flowmeter (2", 55 gpm)				

Agency	City of Tucson (Tucson Parks and Recreation Department) 900 S. Randolph Way Tucson, AZ 85716
Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701
Station Vegetation	D4 Shrubs (E & N) 3rd control box from E
Test or Control?	Test
Water Applicators	Rainbird Xeribird 8 XBD 80, Multi Outlet Emmission Devices with 1 GPH pressure compensation emitters
Applicators per Station	122
GPM per	0.02
Applicator Total Station GPM	2.03

Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701
Station Vegetation	D3 Trees (E & N) 4th control box from E
Test or Control?	Test
Water Applicators	Rainbird Xeribird 8 XBD 80, Multi Outlet Emmission Devices with 1 GPH pressure compensation emitters
Applicators per Station	40
GPM per Applicator	0.02
Total Station GPM	0.67
Note: Site has mainline flowmeter (2", 55 gpm)	

Agency	City of Tucson (Tucson Parks and Recreation Department) 900 S. Randolph Way Tucson, AZ 85716
Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701
Station Vegetation	D5 9 Palo Verde Trees (center courtyard) 5th control box from east
Test or Control?	Control
Water Applicators	Rainbird Xeribird 8 XBD 80, Multi Outlet Emmission Devices with 1 GPH pressure compensation emitters
Applicators per Station	27
GPM per Applicator	0.02
Total Station GPM	0.45

Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701
Station Vegetation	B1 Shrubs (E & SE) 6th control box from east
Test or Control?	Test
Water Applicators	HIT Bubblers (Lindsay, CA) NSF-PW 417 0.25" Nozzles
Applicators per Station	19
GPM per Applicator	0.6
Total Station GPM	11.4
Note: Site has mainline flowmeter (2", 55 gpm)	

Agency	City of Tucson (Tucson Parks and Recreation Department) 900 S. Randolph Way Tucson, AZ 85716
Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701
Station Vegetation	D1 Shrubs (W) 7th control box from east
Test or Control?	Test
Water Applicators	Rainbird Xeribird 8 XBD 80, Multi Outlet Emmission Devices with 1 GPH pressure compensation emitters
Applicators per Station	159
GPM per Applicator	0.02
Total Station GPM	2.65

Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701
Station Vegetation	D2 Trees (W) 8th control box from east
Test or Control?	Test
Water Applicators	Rainbird Xeribird 8 XBD 80, Multi Outlet Emmission Devices with 1 GPH pressure compensation emitters
Applicators per Station	23
GPM per Applicator	0.02
Total Station GPM	0.38
Note: Site has mainline flowmeter (2", 55 gpm)	

Agency	City of Tucson (Tucson Parks and Recreation Department) 900 S. Randolph Way Tucson, AZ 85716					
Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701					
Station Vegetation	S3 Buffalo Grass (W Central & Far W) 9th control box from east					
Test or Control?	Test					
Water Applicators	Rainbird Sprayers, SAM PRS 1804					
	12Q	12T	12H	10F	8F-FLT	
arc	1/4	1/3	1/2	full	full	
Applicators per Station	5 (5 West)	1 (W Cen.)	6 (W Cen.)	1 (Far W.)	1 (W. Cen.)	
GPM per applicator	1	1.33	2	4	4	
Total Station GPM	26.33					
Prec. rate (in/hr)	2					

Site (Potable water)	Sunset Park (City Hall) 255 W. Alameda Tucson, AZ 85701
Station Vegetation	B3 Trees and Shrubs (SW) 10th control box from east
Test or Control?	Control
Water Applicators	HIT Bubblers (Lindsay, CA) NSF-PW 417 0.25" Nozzles
Applicators per Station	8
GPM per Applicator	0.6
Total Station GPM	4.8
Note: Site has mainline flowmeter (2", 55 gpm)	

Agency	Reid Park Zoo (Tucson Parks and Recreation Department) 900 S. Randolph Way Tucson, AZ 85716	
Site (Reclained water)	Reid Park Zoo 1100 S. Randolph Way Tucson, AZ 85716	
Station Vegetation	5 Bermuda or Rye Grass Savana (birds)	2 Bermuda or Rye Grass Giraffe display
Test or Control?	test	test
Water Applicators	Toro Sprinklers 50 psi, 640 Series (full arc)	Hunter Sprinklers 50 psi, I-40 (full arc)
Applicators per sta.	3	2
GPM per applicator	12.9	8.0
Total Station GPM	38.7	16.0
Applic. spacing (ft)	55 Triangular	40 Square
Precip. rate (in/hr)	0.39	0.48

Site (Reclained water)	Reid Park Zoo 1100 S. Randolph Way Tucson, AZ 85716	
Station Vegetation	1 Baboon stalks Mandril guardrail	3 Privots Turtle yard
Test or Control?	test	test
Water Applicators	Toro Sprayers 50 psi, 570 Series shrub head body (15'rad)	Toro Bubblers 50 psi, 514-20 Series
Applicators per Station	18	20
GPM per Applicator	1.4	2.7
Total Station GPM	25.2	54
Notes: Water supply conversion from lake water (as of 7-2-96, 50 psi) to effluent. Effluent from 12" line across 22nd St.; this line is currently 102 psi and this source will likely be reduced to 85 psi.		

Agency	Reid Park Zoo (Tucson Parks and Recreation Department) 900 S. Randolph Way Tucson, AZ 85716	
Site (Reclained water)	Reid Park Zoo 1100 S. Randolph Way Tucson, AZ 85716	
Station Vegetation	2 Privots Wall by peacock cage	Gift shop, no timer yet Bermuda or Rye Grass
Test or Control?	Test	Test
Water Applicators	Toro Bubblers 50 psi, 514-20 Series	Toro Sprayers 50 psi, 570 15-H (1/2 arc)
Applicators per Station	16	9
GPM per Applicator	2.7	2.14
Total Station GPM	43.2	19.3
Notes: Water supply conversion from lake water (as of 7-2-96, 50 psi) to effluent. Effluent from 12" line across 22nd St.; this line is currently 102 psi and this source will likely be reduced to 85 psi.		

APPENDIX E: REFERENCE VOLTAGES

Final reference voltage settings reflect the adjustment where the number of irrigation cycles were skipped to prevent both overwatering and plant stress. These are tabulated in Tables E.1 to E.5 according to sprinkler, bubbler, and emitter stations, and whether these stations were irrigated with potable or reclaimed water. The six sprinkler sites excluded from the analyses of Section 5.2 are also excluded here.

Most sprinkler sites and all emitter sites that were irrigated with potable water generally had final reference voltage settings of 9 volts, with the following exceptions. Reference voltages at the two sprinkler stations at Sunset Park were increased to 10.5 and 11 volts on September 20, shortly after installation of the modified overwatering controller design. The Sunset Park stations are the only sites where buffalo grass is planted; consequently, no comparisons could be made with other stations in this regard.

Two sprinkler stations at Las Palmas Apartments were eliminated from the analyses of Section 5.2 because of difficulties with timers. Occasional timer difficulties were also experienced at the remaining two stations; however, data from these stations were deemed reliable enough for analysis. The reference voltage settings of 7

and 10 volts were found to minimize timer malfunctions. As stated earlier, the exact cause of the timer malfunctions has not been determined.

In the case of the two bubbler stations at Hudlow Elementary School, excessive dryness of trees and soil was noted on November 16; this corresponded to an unusually high number of irrigation cycles being skipped. Reference voltages were then increased from 9 to 11 volts on that date. The cause of the sudden increase in skipped irrigation cycles at Hudlow has not been determined.

Final reference voltage settings at sprinkler sites irrigated with reclaimed water were also generally 9 volts; however, these sites were noted in the previous section as subject to excessive spray from adjacent stations or runoff from other areas. It is possible that leaching at these sites may have reduced soil salinity. This in turn may have prevented soil probe low side potentials from increasing much above those at sites irrigated with potable water. At sites where neither spray or runoff likely influenced depths applied, final reference voltages ranged from 10 to 11 volts. This is with the exception of Ft. Lowell Elementary School, where timer settings were below ETa and required depths. Final reference voltage settings at the two bubbler stations at the Reid Park Zoo were 10 and 11.5 volts.

Table E.1:
Reference voltages for sprinkler sites irrigated with potable water

Site	Sta.	Vegetation	Final Ref V.
Arthur Pack Reg. Pk.	3	Bermuda grass	9
Arthur Pack Reg. Pk.	5	Bermuda grass	9
Arthur Pack Reg. Pk.	9	Bermuda grass	9
Arthur Pack Reg. Pk.	13	Bermuda grass	9
Hudlow Ele. Sch.	7	Bermuda grass	9
Hudlow Ele. Sch.	13	Bermuda grass	9
Hudlow Ele. Sch.	14	Bermuda grass	9
Las Palmas Apts.	2f	Bermuda or rye grass	10
Las Palmas Apts.	1	Bermuda or rye grass	7
Sunset Park	S1	Buffalo grass	10.5
Sunset Park	S3	Buffalo grass	11

Table E.2:
Reference voltages for bubbler sites irrigated with potable water

Site	Sta.	Vegetation	Final Ref V.
Hudlow Ele. Sch.	1	Trees	11
Hudlow Ele. Sch.	16	Trees	11
Sunset Park	B1	Shrubs	9

Table E.3:
Reference voltages for emitter sites irrigated with potable water

Site	Sta.	Vegetation	Final Ref V.
Aviation Bikeway	13T	Trees	9
Aviation Bikeway	14S	Shrubs	9
Kostrzewski Res.	1	Flowers	9
Kostrzewski Res.	2	Vegetables	9
Sunset Park	D4	Shrubs	9
Sunset Park	D3	Trees	9
Sunset Park	D1	Shrubs	9
Sunset Park	D2	Trees	9

Table E.4:
Reference voltages for sprinkler sites irrigated with reclaimed water

Site	Sta.	Vegetation	Final Ref V.
Cardinal Park	3	Bermuda grass	10
Ft. Lowell Ele. Sch.	C-8	Bermuda grass	9
Ft. Lowell Ele. Sch.	C-10	Bermuda grass	9
Ft. Lowell Ele. Sch.	C-12	Bermuda grass	9
Ft. Lowell Ele. Sch.	C-14	Bermuda grass	9
Ft. Lowell Ele. Sch.	C-17	Bermuda grass	9
Lawrence Park	3	Bermuda grass	9
Meadowbrook Park	1	Bermuda grass	8
Meadowbrook Park	16	Bermuda grass	9
Mission Ridge Park	10	Bermuda grass	10.5
Mission Ridge Park	10	Bermuda grass	11
Myers-Ganoung Ele. Sch.	13	Bermuda grass	9
Myers-Ganoung Ele. Sch.	14	Bermuda grass	9
Myers-Ganoung Ele. Sch.	1	Bermuda grass	9
Myers-Ganoung Ele. Sch.	2	Bermuda grass	9
Myers-Ganoung Ele. Sch.	5	Bermuda grass	9
Richardson Park	4	Bermuda grass	10
Richardson Park	5	Bermuda grass	9
Reid Park Zoo	5	Bermuda grass	10
Reid Park Zoo	2	Bermuda grass	11

Table E.5:
Reference voltages for bubbler sites irrigated with reclaimed water

Site	Sta.	Vegetation	Final Ref V.
Reid Park Zoo	3	Trees	10
Reid Park Zoo	2	Trees	11.5

APPENDIX F: WATER VOLUME AND CYCLE TIME TABLES

Table F 1a: Volumes of water savings for sprinkler stations (Fall 1996).

Site	Sta.	Est. gpm per Sta.	Gallons Saved	Gallons Applied	Gallons Potential	Percent Savings
Arthur Pack Reg. Pk.	3	106.5	0	59,640	59,640	0%
Arthur Pack Reg. Pk.	5	127.8	40,900	30,670	71,570	57%
Arthur Pack Reg. Pk.	9	63	16,380	18,900	35,280	46%
Arthur Pack Reg. Pk.	13	63	22,050	13,230	35,280	63%
Cardinal Pk.	3	37.6	13,160	13,910	27,070	49%
Ft. Lowell Elem. Sch.	C-8	56	0	13,440	13,440	0%
Ft. Lowell Elem. Sch.	C-10	72	0	17,280	17,280	0%
Ft. Lowell Elem. Sch.	C-12	72	0	17,280	17,280	0%
Ft. Lowell Elem. Sch.	C-14	72	0	17,280	17,280	0%
Ft. Lowell Elem. Sch.	C-17	72	0	17,280	17,280	0%
Hudlow Elem. Sch.	7	48	13,440	28,800	42,240	32%
Hudlow Elem. Sch.	13	48	1,920	40,320	42,240	5%
Hudlow Elem. Sch.	14	48	11,520	30,720	42,240	27%
Lawrence Pk.	3	43.2	15,980	13,400	29,380	54%
Meadowbrook Pk.	1	54	7,560	38,880	46,440	16%
Meadowbrook Pk.	16	72	15,840	46,080	61,920	26%
Mission Ridge Pk.	9	27.3	13,380	10,370	23,750	56%
Mission Ridge Pk.	10	58	23,780	26,680	50,460	47%
Myers Elem. Sch.	13	24	8,640	9,360	18,000	48%
Myers Elem. Sch.	14	32	9,600	14,400	24,000	40%
Myers Elem. Sch.	1	40	8,400	21,600	30,000	28%
Myers Elem. Sch.	2	32	19,200	4,800	24,000	80%
Myers Elem. Sch.	5	40	28,800	1,200	30,000	96%
Las Palmas Apts. (2)	2f	12.5	1,880	3,870	5,750	33%
Las Palmas Apts. (2)	1	11.1	2,330	4,440	6,770	34%
Richardson Pk.	4	57.6	21,890	23,610	45,500	48%
Richardson Pk.	5	56.8	16,470	28,400	44,870	37%
Sunset Pk. (3)	S1	16.66	5,000	3,160	8,160	61%
Sunset Pk. (3)	S3	26.33	7,900	5,000	12,900	61%
Reid Park Zoo (2)	5	38.7	12,380	25,930	38,310	32%
Reid Park Zoo (2)	2	16	2,400	8,640	11,040	22%
Totals		**Gallons**	**340,800**	**608,570**	**949,370**	**35%**
		Acre-Ft	1.05	1.87	2.91	

Notes. (1) Vegetation is Bermuda grass except for cases (2) and (3).

(2) Bermuda grass until mid-October; re-seeded with Rye grass thereafter

(3) Buffalo grass planted late March 1996

Table F.1b: Volumes of water savings for bubbler stations (Fall 1996).

Site	Sta.	Est.gpm perSta.	Gallons Saved	Gallons Applied	Gallons Potential	Percent Savings
Hudlow Elem. Sch.	1	43	8,600	29,240	37,840	**23%**
Hudlow Elem. Sch.	16	14	3,360	8,960	12,320	**27%**
Sunset Pk.	B1	11.4	0	2,390	2,390	**0%**
Reid Park Zoo	3	54	7,560	24,840	32,400	**23%**
Reid Park Zoo	2	43.2	6,910	19,010	25,920	**27%**
	Totals	**Gallons**	**26,430**	**84,440**	**110,870**	**25%**
		Acre-Ft	0.08	0.26	0.34	

Table F.1c: Volumes of water savings for emitter stations (Fall 1996).

Site	Sta.	Est. gpm per Sta.	Gallons Saved	Gallons Applied	Gallons Potential	Percent Savings
Aviation Bikeway	13T	2.80	5,040	12,100	17,140	**29%**
Aviation Bikeway	14S	2.20	1,320	9,640	10,960	**12%**
Kostrzewski Res.	1	6.50	1,500	11,180	12,680	**12%**
Kostrzewski Res.	2	2.50	380	2,870	3,250	**12%**
Sunset Pk.	D4	2.00	2,640	3,600	6,240	**42%**
Sunset Pk.	D3	0.67	0	2,090	2,090	**0%**
Sunset Pk.	D1	2.65	3,500	4,770	8,270	**42%**
Sunset Pk.	D2	0.38	640	550	1,190	**54%**
	Totals	**Gallons**	**15,020**	**46,800**	**61,820**	**25%**
		Acre-Ft	0.05	0.14	0.19	

Table F.1d: Summary of water savings during Fall 1996 (total gallons).

Irrigation Method	Saved	Applied	Potential	Savings
Sprinklers (n = 31)	340,800	608,570	949,370	**35%**
Bubblers (n = 5)	26,430	84,440	110,870	**25%**
Emitters (n = 8)	15,020	46,800	61,820	**25%**
Totals	**382,250**	**739,810**	**1,122,060**	**35%**

Table F.2a: Irrigation times for sprinkler stations (Fall 1996).

Site	Sta.	Irr. Times (min) Skipped	Potential	Percent Skipped
Arthur Pack Reg. Pk.	3	0	560	0%
Arthur Pack Reg. Pk.	5	320	560	57%
Arthur Pack Reg. Pk.	9	260	560	46%
Arthur Pack Reg. Pk.	13	350	560	63%
Cardinal Pk.	3	350	720	49%
Ft. Lowell Elem. Sch.	C-8	0	240	0%
Ft. Lowell Elem. Sch.	C-10	0	240	0%
Ft. Lowell Elem. Sch.	C-12	0	240	0%
Ft. Lowell Elem. Sch.	C-14	0	240	0%
Ft. Lowell Elem. Sch.	C-17	0	240	0%
Hudlow Elem. Sch.	7	280	880	32%
Hudlow Elem. Sch.	13	40	880	5%
Hudlow Elem. Sch.	14	240	880	27%
Lawrence Pk.	3	370	680	54%
Meadowbrook Pk.	1	140	860	16%
Meadowbrook Pk.	16	220	860	26%
Mission Ridge Pk.	9	490	870	56%
Mission Ridge Pk.	10	410	870	47%
Myers Elem. Sch.	13	360	750	48%
Myers Elem. Sch.	14	300	750	40%
Myers Elem. Sch.	1	210	750	28%
Myers Elem. Sch.	2	600	750	80%
Myers Elem. Sch.	5	720	750	96%
Las Palmas Apts. (2)	2f	150	460	33%
Las Palmas Apts. (2)	1	210	610	34%
Richardson Pk.	4	380	790	48%
Richardson Pk.	5	290	790	37%
Sunset Pk. (3)	S1	300	490	61%
Sunset Pk. (3)	S3	300	490	61%
Reid Park Zoo (2)	5	320	990	32%
Reid Park Zoo (2)	2	150	690	22%
Totals	**(min)**	**7,760**	**20,000**	**40%**
			Mean =	**35%**
			Med. =	**35%**

Notes: (1) Vegetation is Bermuda grass except for cases (2) and (3).
(2) Bermuda grass until mid-October; re-seeded with Rye grass thereafter
(3) Buffalo grass planted late March 1996.

Table F.2b: Irrigation times for bubbler stations (Fall 1996).

Site	Sta.	Irr. Times (min) Skipped	Potential	Percent Skipped
Hudlow Elem. Sch.	1	200	880	**23%**
Hudlow Elem. Sch.	16	240	880	**27%**
Sunset Pk.	B1	0	210	**0%**
Reid Park Zoo	3	140	600	**23%**
Reid Park Zoo	2	160	600	**27%**
Totals	**(min)**	**740**	**3,170**	**25%**
			Mean =	**20%**
			Med. =	**25%**

Table F.2c: Irrigation times for emitter stations (Fall 1996).

Site	Sta.	Irr. Times (min) Skipped	Potential	Percent Skipped
Aviation Bikeway	13T	1,800	6,120	**29%**
Aviation Bikeway	14S	600	4,980	**12%**
Kostrzewski Res.	1	230	1,950	**12%**
Kostrzewski Res.	2	150	1,300	**12%**
Sunset Pk.	D4	1,320	3,120	**42%**
Sunset Pk.	D3	0	3,120	**0%**
Sunset Pk.	D1	1,320	3,120	**42%**
Sunset Pk.	D2	1,680	3,120	**54%**
Totals	**(min)**	**7,100**	**26,830**	**25%**
			Mean =	**25%**
			Med. =	**20%**

Table F.2d: Summary of skipped irrigation times during Fall 1996 (total minutes).

Irrigation Method	Irr. Times (min) Skipped	Potential	Percent Skipped	Mean	Med.
Sprinklers (n = 31)	7,760	20,000	40%	35%	35%
Bubblers (n = 5)	740	3,170	25%	20%	25%
Emitters (n = 8)	7,100	26,830	25%	25%	20%
Totals	**15,600**	**50,000**	**30%**	**30%**	**30%**

APPENDIX G: SUMMARY OF TOTAL DEPTHS AT SPRINKLER STATIONS

Table G.1 tabulates sprinkler application rates, the sums of depths saved, actual depths applied, potential depths applied (timer set depths that would have been applied without using the overwatering controller), and percent savings for the 31 sprinkler stations from September to November 1996. Table G.2 tabulates evapotranspiration (ETa) for the sprinkler stations, the resulting actual depths applied in excess of evapotranspiration, and the potential depths applied in excess of evapotranspiration. Table G.3 is similar to Table G.2 except rainfall is included to the estimated irrigation requirement (evapotranspiration minus rain). The resulting actual depths applied in excess of the irrigation requirement and the potential depths applied in excess of the irrigation requirement are tabulated. Most stations show that the potential depths were in excess of the irrigation requirement (Table G.3); potential depths in excess of evapotranspiration were slightly less frequent (Table G.2).

Runoff may have resulted in actual depths applied being in excess of evapotranspiration. This was the case for three stations; these were Arthur Pack Regional Park (Station 3), and the two stations at Las Palmas Apartments. The irrigated areas at these stations are on noticeable slopes, and runoff was observed many times. In addition,

the Las Palmas stations have high sprinkler application rates of 1.5 and 1.6 inches per hour (Table G.1).

When estimated precipitation is considered, actual depths applied exceeded the irrigation requirement at eight stations (Table G.3). These are the three stations just mentioned, and Meadowbrook Park (Station 1), Myers Elementary School (Stations 13 and 1), and the two stations at Sunset Park. The two Sunset Park stations are also on noticeable slopes and have high sprinkler application rates of 2 inches per hour. The Meadowbrook and Myers stations, however, are flat and have much lower sprinkler application rates. Meadowbrook Park is actually located in a flood retention basin. Either errors in estimated rainfall excessively lowered the irrigation requirement (see Section 5.2), or the overwatering controller did not skip a sufficient number of irrigation cycles, or both.

The majority of stations showed actual depths applied below both evapotranspiration and estimated irrigation requirements. This was most noticeable at the five stations at Ft. Lowell Elementary School. At these stations, the timer was set to apply water only once a week for 40 minutes. Consequently, the potential depths were well below evapotranspiration and plant requirements, and no irrigation cycles were skipped.

Several other factors likely contributed to actual depths applied being below both evapotranspiration and irrigation requirements. These include overspray from adjacent stations, runoff from other areas reducing irrigation requirements, and initial reference voltages set too low so that too many irrigation cycles were skipped. Sprinklers at Myers Elementary School overlapped test stations very noticeably; consequently, these test stations were subject to spray from adjacent stations where overwatering controllers were not installed. Many stations and sprinklers within stations at Myers appeared to be redundant. Nearly all irrigation cycles were skipped at station 5, for example; this station was especially overlapped by an adjacent station. Station 5 also had the highest application rate for this study of 2.45 inches per hour. This rate does not include spray from the adjacent station. Soil probe placement outside of overlapping zones was usually not feasible at the Myers test stations.

Runoff from other areas was noticeable at Arthur Pack Regional Park (except Station 3), Cardinal Park, Hudlow Elementary School, Meadowbrook Park (located in a flood retention basin), and Richardson Park. Although Meadowbrook Park can accumulate and hold up to several feet of water following a rainfall event, the applied depth at Station 1 was in excess of the required depth. The applied depth at

Station 16, however, matched the required depth and was below evapotranspiration by 1.3 inches.

Finally, reference voltage settings had to be increased at many stations because too many irrigation cycles were skipped when the modified overwatering controller design was first installed. This was most noticeable at Mission Ridge Park and the Reid Park Zoo which are irrigated with reclaimed water. Reclaimed water has a higher electrical conductivity, meaning than low side potentials of the soil probe would be greater than probes at sites irrigated with potable water. From Appendix D, other sprinkler sites irrigated with reclaimed water include Cardinal Park, Lawrence Park, Ft. Lowell Elementary School, Meadowbrook Park, Myers Ganoung Elementary School, and Richardson Park. Reference voltages at many of these sites had to be increased to 11 volts (the soil probe high side potential is 12 volts) to prevent continued water stress of vegetation. Final reference voltage settings are discussed further in Appendix E.

Table G.1: Water depths at sprinkler stations during Fall 1996.

Site	Sta.	Appl. rate (in/hr)	Saved (in)	Applied (in)	Potential (in)	Percent Savings
Arthur Pack Reg. Pk.	3	0.81	0.0	7.6	7.6	**0%**
Arthur Pack Reg. Pk.	5	0.81	4.3	3.2	7.6	**57%**
Arthur Pack Reg. Pk.	9	0.78	3.4	3.9	7.3	**46%**
Arthur Pack Reg. Pk.	13	0.78	4.6	2.7	7.3	**63%**
Cardinal Pk.	3	0.43	2.5	2.7	5.2	**49%**
Ft. Lowell Elem. Sch.	C-8	0.21	0.0	0.8	0.8	**0%**
Ft. Lowell Elem. Sch.	C-10	0.21	0.0	0.8	0.8	**0%**
Ft. Lowell Elem. Sch.	C-12	0.24	0.0	1.0	1.0	**0%**
Ft. Lowell Elem. Sch.	C-14	0.24	0.0	1.0	1.0	**0%**
Ft. Lowell Elem. Sch.	C-17	0.24	0.0	1.0	1.0	**0%**
Hudlow Elem. Sch.	7	0.25	1.2	2.5	3.7	**32%**
Hudlow Elem. Sch.	13	0.25	0.2	3.5	3.7	**5%**
Hudlow Elem. Sch.	14	0.25	1.0	2.7	3.7	**27%**
Lawrence Pk.	3	0.47	2.9	2.4	5.3	**54%**
Meadowbrook Pk.	1	0.4	0.9	4.8	5.7	**16%**
Meadowbrook Pk.	16	0.4	1.5	4.3	5.7	**26%**
Mission Ridge Pk.	9	0.36	2.9	2.3	5.2	**56%**
Mission Ridge Pk.	10	0.36	2.5	2.8	5.2	**47%**
Myers Elem. Sch.	13	0.86	5.2	5.6	10.8	**48%**
Myers Elem. Sch.	14	0.59	3.0	4.4	7.4	**40%**
Myers Elem. Sch.	1	0.59	2.1	5.3	7.4	**28%**
Myers Elem. Sch.	2	0.78	7.8	1.9	9.8	**80%**
Myers Elem. Sch.	5	2.45	29.4	1.2	30.6	**96%**
Las Palmas Apts. (2)	2f	1.49	3.7	7.7	11.4	**33%**
Las Palmas Apts. (2)	1	1.6	5.6	10.7	16.3	**34%**
Richardson Pk.	4	0.45	2.9	3.1	5.9	**48%**
Richardson Pk.	5	0.45	2.2	3.7	5.9	**37%**
Sunset Pk. (3)	S1	2	10.0	6.3	16.3	**61%**
Sunset Pk. (3)	S3	2	10.0	6.3	16.3	**61%**
Reid Park Zoo (2)	5	0.39	2.1	4.4	6.4	**32%**
Reid Park Zoo (2)	2	0.48	1.2	4.3	5.5	**22%**
Totals		**(in)**	**113**	**115**	**228**	**50%**
Means		**(in)**	**3.6**	**3.7**	**7.3**	**35%**
Medians		**(in)**	**2.5**	**3.2**	**5.9**	**35%**

Notes: (1) Vegetation is Bermuda grass except for cases (2) and (3).
(2) Bermuda grass until mid-October; re-seeded with Rye grass thereafter
(3) Buffalo grass planted late March 1996.

Table G.2: Water depths (applied and potential from Table G.1) in excess of ETa. Does not include precipitation. Positive excess values imply overwatering.

Site	Sta.	ETa (in)	Applied Excess (in)	Potential Excess (in)
Arthur Pack Reg. Pk.	3	5.2	2.3	2.3
Arthur Pack Reg. Pk.	5	5.2	-2.0	2.3
Arthur Pack Reg. Pk.	9	5.2	-1.3	2.1
Arthur Pack Reg. Pk.	13	5.1	-2.3	2.2
Cardinal Pk.	3	5.4	-2.7	-0.2
Ft. Lowell Elem. Sch.	C-8	5.3	-4.5	-4.5
Ft. Lowell Elem. Sch.	C-10	5.3	-4.5	-4.5
Ft. Lowell Elem. Sch.	C-12	5.3	-4.3	-4.3
Ft. Lowell Elem. Sch.	C-14	5.3	-4.3	-4.3
Ft. Lowell Elem. Sch.	C-17	5.3	-4.3	-4.3
Hudlow Elem. Sch.	7	6.0	-3.5	-2.3
Hudlow Elem. Sch.	13	6.0	-2.5	-2.3
Hudlow Elem. Sch.	14	6.0	-3.3	-2.3
Lawrence Pk.	3	5.5	-3.1	-0.2
Meadowbrook Pk.	1	5.6	-0.8	0.2
Meadowbrook Pk.	16	5.6	-1.3	0.2
Mission Ridge Pk.	9	5.4	-3.1	-0.1
Mission Ridge Pk.	10	5.4	-2.6	-0.1
Myers Elem. Sch.	13	6.9	-1.3	3.9
Myers Elem. Sch.	14	6.9	-2.4	0.5
Myers Elem. Sch.	1	6.9	-1.6	0.5
Myers Elem. Sch.	2	6.9	-4.9	2.9
Myers Elem. Sch.	5	6.9	-5.6	23.8
Las Palmas Apts. (2)	2f	5.4	2.3	6.0
Las Palmas Apts. (2)	1	5.4	5.3	10.9
Richardson Pk.	4	6.3	-3.2	-0.3
Richardson Pk.	5	6.3	-2.5	-0.3
Sunset Pk. (3)	S1	7.2	-0.8	9.2
Sunset Pk. (3)	S3	7.2	-0.8	9.2
Reid Park Zoo (2)	5	7.0	-2.6	-0.6
Reid Park Zoo (2)	2	7.0	-2.7	-1.5
Totals	**(in)**	**184**	**-69**	**44**
Means	**(in)**	**5.9**	**-2.2**	**1.4**
Medians	**(in)**	**5.6**	**-2.6**	**-0.1**

Notes. (1) Vegetation is Bermuda grass except for cases (2) and (3).
(2) Bermuda grass until mid-October, re-seeded with Rye grass thereafter
(3) Buffalo grass planted late March 1996

Table G.3 Water depths (applied and potential from Table G.1) in excess of plant requirement (ETa - Rain). Precipitation data is from AZMET CAC. Positive excess values imply overwatering.

Site	Sta.	ETa (in)	Rain (in)	Applied Excess (in)	Potential Excess (in)
Arthur Pack Reg. Pk.	3	5.2	1.3	3.6	3.6
Arthur Pack Reg. Pk.	5	5.2	1.3	-0.7	3.6
Arthur Pack Reg. Pk.	9	5.2	1.3	-0.0	3.4
Arthur Pack Reg. Pk.	13	5.1	1.3	-1.0	3.5
Cardinal Pk.	3	5.4	1.2	-1.5	1.0
Ft. Lowell Elem. Sch.	C-8	5.3	2.2	-2.2	-2.2
Ft. Lowell Elem. Sch.	C-10	5.3	2.2	-2.2	-2.2
Ft. Lowell Elem. Sch.	C-12	5.3	2.2	-2.1	-2.1
Ft. Lowell Elem. Sch.	C-14	5.3	2.2	-2.1	-2.1
Ft. Lowell Elem. Sch.	C-17	5.3	2.2	-2.1	-2.1
Hudlow Elem. Sch.	7	6.0	2.2	-1.2	-0.0
Hudlow Elem. Sch.	13	6.0	2.2	-0.2	-0.0
Hudlow Elem. Sch.	14	6.0	2.2	-1.0	-0.0
Lawrence Pk.	3	5.5	1.2	-1.8	1.1
Meadowbrook Pk.	1	5.6	1.3	0.5	1.5
Meadowbrook Pk.	16	5.6	1.3	-0.0	1.5
Mission Ridge Pk.	9	5.4	1.2	-1.8	1.1
Mission Ridge Pk.	10	5.4	1.2	-1.4	1.1
Myers Elem. Sch.	13	6.9	2.2	1.0	6.1
Myers Elem. Sch.	14	6.9	2.2	-0.2	2.7
Myers Elem. Sch.	1	6.9	2.2	0.7	2.7
Myers Elem. Sch.	2	6.9	2.2	-2.7	5.1
Myers Elem. Sch.	5	6.9	2.2	-3.4	26.0
Las Palmas Apts. (2)	2f	5.4	2.2	4.5	8.3
Las Palmas Apts. (2)	1	5.4	2.2	7.5	13.1
Richardson Pk.	4	6.3	1.3	-1.9	1.0
Richardson Pk.	5	6.3	1.3	-1.2	1.0
Sunset Pk. (3)	S1	7.2	2.2	1.4	11.4
Sunset Pk. (3)	S3	7.2	2.2	1.4	11.4
Reid Park Zoo (2)	5	7.0	2.2	-0.4	1.7
Reid Park Zoo (2)	2	7.0	2.2	-0.4	0.8
Totals	**(in)**	**184**	**58**	**-11**	**102**
Means	**(in)**	**5.9**	**1.9**	**-0.4**	**3.3**
Medians	**(in)**	**5.6**	**2.2**	**-1.0**	**1.5**

Notes: (1) Vegetation is Bermuda grass except for cases (2) and (3)
(2) Bermuda grass until mid-October; re-seeded with Rye grass thereafter
(3) Buffalo grass planted late March 1996

APPENDIX H: WEEKLY DEPTHS AT SPRINKLER STATIONS

Appendix H contains weekly depth data for sprinkler stations where overwatering controllers were installed. Potential depths of water applied were estimated based on station application rates from Appendix D and weekly irrigation schedules. Depths saved were estimated based on the number of pulse counts (irrigation cycles skipped) on the overwatering controller; the pulse counts were read at weekly visits to each site. Actual depths of water applied were the potential depths minus the saved depths.

Evapotranspiration and precipitation data were taken from the Arizona Meteorological Network (AZMET) Tucson station. This station is located at the University of Arizona Campus Agricultural Center (CAC) in the north central area of the city.

Each column in Appendix H is labeled using a capital letter; columns involving calculations show the algebraic formula in terms of the capital letters of the other columns. The parameters calculated herein were used in analyzing data for the results discussed in Chapter 5.

Site Pima [illegible], Community Resources
Arthur Pack Regional Park
9101 [illegible] Mainydale Rd
Tucs[illegible]

Station / Vegetation / Description
Station 3
Bermuda grass
Left outfield north fence

Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-13-96	0 [illegible]	15	1	3	0.61	0 56	0 65	0 36	0 05	0.31	0	3	0 00	0.61	0 29	0 29
9-20-96	0 [illegible]	15	1	7	1.42	1 57	0 65	1 02	0 00	1.02	0	7	0 00	1.42	0 40	0 40
9-27-96	0 [illegible]	15	1	7	1.42	1 33	0 65	0 86	1 21	-0.34	0	7	0 00	1.42	1 76	1 76
10 4-96	0 [illegible]	15	1	7	1.42	1 58	0 65	1 03	0 00	1.03	0	7	0 00	1.42	0 39	0 39
10-11 96	0 [illegible]	15	1	7	1.42	1 64	0 65	1 07	0 00	1.07	0	7	0 00	1.42	0 35	0 35
10-17-96	0 [illegible]	15	1	6	1.22	1 35	0 65	0 88	0 04	0.84	0	6	0 00	1.22	0 38	0 38

Site Pima [illegible], Community Resources
Arthur Pack Regional Park
9101 [illegible] Mainydale Rd
Tucs[illegible]

Station / Vegetation / Description
Station 5
Bermuda grass
Left infield north and west fence

Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-13-96	0 [illegible]	15	1	3	0.61	0 56	0 65	0 36	0 05	0.31	2	1	0 41	0.20	0 29	-0 11
9-20-96	0 [illegible]	15	1	7	1.42	1 57	0 65	1 02	0 00	1.02	3	4	0 61	0.81	0 40	-0 21
9-27-96	0 [illegible]	15	1	7	1.42	1 33	0 65	0 86	1 21	-0.34	3	4	0 61	0.81	1 76	1 15
10-4-96	0 [illegible]	15	1	7	1.42	1 58	0 65	1 03	0 00	1.03	6	1	1 22	0.20	0 39	-0 82
10-11 96	0 [illegible]	15	1	7	1.42	1 64	0 65	1 07	0 00	1.07	4	3	0 81	0.61	0 35	-0 46
10 17 96	0 [illegible]	15	1	6	1.22	1 35	0 65	0 88	0 04	0.84	3	3	0 61	0.61	0 38	-0 23

Site	Pima County Community Resources Arthur Pack Regional Park 9101 N Thornydale Rd Tucson AZ					Station / Vegetation / Description Station 9 Bermuda grass Right infield west fence										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-13-96	0 78	15	1	3	0.59	0 56	0 65	0 36	0 05	0.31	2	1	0 39	0.20	0 27	-0 12
9-20-96	0 78	15	1	7	1.37	1 57	0 65	1 02	0 00	1.02	4	3	0 78	0.59	0 34	-0 44
9-27-96	0 78	15	1	7	1.37	1 33	0 65	0 86	1 21	-0.34	2	5	0 39	0.98	1 71	1 32
10-4-96	0 78	15	1	7	1.37	1 58	0 65	1 03	0 00	1.03	6	1	1 17	0.20	0 34	-0 83
10-11-96	0 78	15	1	7	1.37	1 64	0 65	1 07	0 00	1.07	3	4	0 59	0.78	0 30	-0 29
10-17-96	0 78	15	1	6	1.17	1 35	0 65	0 88	0 04	0.84	0	6	0 00	1.17	0 33	0 33

Site	Pima County Community Resources Arthur Pack Regional Park 9101 N Thornydale Rd Tucson AZ					Station / Vegetation / Description Station 13 Bermuda grass Right outfield south fence										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-13-96	0 78	15	1	3	0.59	0 56	0 65	0 36	0 05	0.31	2	1	0 39	0.20	0 27	-0 12
9-20-96	0 78	15	1	7	1.37	1 57	0 65	1 02	0 00	1.02	4	3	0 78	0.59	0 34	-0 44
9-27-96	0 78	15	1	7	1.37	1 33	0 65	0 86	1 21	-0.34	3	4	0 59	0.78	1 71	1 12
10-4-96	0 78	15	1	7	1.37	1 58	0 65	1 03	0 00	1.03	6	1	1 17	0.20	0 34	-0 83
10-11-96	0 78	15	1	7	1.37	1 64	0 65	1 07	0 00	1.07	3	4	0 59	0.78	0 30	-0 29
10-17-96	0 78	15	1	6	1.17	1 11	0 65	0 72	0 04	0.68	5	1	0 98	0.20	0 49	-0 49

Site	Pima County Community Resources Cardinal Park 6925 S Cardinal Ave Tucson, AZ					Station / Vegetation / Description Station 3 Bermuda grass North side along path next to fence										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl. (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0.43	35	1	5	1.25	1.57	0.65	1.02	0.00	1.02	3	2	0.75	0.50	0.23	-0.52
9-27-96	0.43	35	1	5	1.25	1.57	0.65	1.02	0.00	1.02	3	2	0.75	0.50	0.23	-0.52
10-2-96	0.43	23	1	3	0.49	1.11	0.65	0.72	0.00	0.72	1	2	0.16	0.33	-0.22	-0.39
10-11-96	0.43	23	1	7	1.15	2.11	0.65	1.37	0.00	1.37	4	3	0.66	0.49	-0.22	-0.88
10-19-96	0.43	23	1	5	0.82	1.50	0.65	0.97	0.04	0.93	1	4	0.16	0.66	0.11	-0.28
10-21-96	0.43	23	1	1	0.16	0.39	0.65	0.26	0.00	0.26	0	1	0.00	0.16	-0.09	-0.09

Site	Ft Lowell Elementary School 5151 E Pima (Between Swan and Craycroft) Tucson, AZ 85712					Station / Vegetation / Description C-8 Bermuda grass North of East parking lot (West Central Area)										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl. (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-27-96	0.21	40	1	1	0.14	1.33	0.65	0.86	1.21	-0.34	0	1	0.00	0.14	0.48	0.48
10-4-96	0.21	40	1	1	0.14	1.58	0.65	1.03	0.00	1.03	0	1	0.00	0.14	-0.89	-0.89
10-11-96	0.21	40	1	1	0.14	1.64	0.65	1.07	0.00	1.07	0	1	0.00	0.14	-0.93	-0.93
10-19-96	0.21	40	1	1	0.14	1.50	0.65	0.97	0.04	0.93	0	1	0.00	0.14	-0.79	-0.79
10-26-96	0.21	40	1	1	0.14	1.40	0.65	0.91	0.00	0.91	0	1	0.00	0.14	-0.77	-0.77
11-2-96	0.21	40	1	1	0.14	0.71	0.65	0.46	0.99	-0.53	0	1	0.00	0.14	0.67	0.67

Site	Ft Lowell Elementary School 5151 E Pima (Between Swan and Craycroft) Tucson AZ 85712					Station / Vegetation / Description C-10 Bermuda grass Second station north of C-8										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-27-96	0 21	40	1	1	0.14	1 33	0 65	0 86	1 21	-0.34	0	1	0 00	0.14	0 48	0 48
10-4 96	0 21	40	1	1	0.14	1 58	0 65	1 03	0 00	1.03	0	1	0 00	0.14	-0 89	-0 89
10-11-96	0 21	40	1	1	0.14	1 64	0 65	1 07	0 00	1.07	0	1	0 00	0.14	-0 93	0 93
10-19-96	0 21	40	1	1	0.14	1 50	0 65	0 97	0 04	0.93	0	1	0 00	0.14	-0 79	0 79
10 26-96	0 21	40	1	1	0.14	1 40	0 65	0 91	0 00	0.91	0	1	0 00	0.14	-0 77	0 77
11-2-96	0 21	40	1	1	0.14	0 71	0 65	0 46	0 99	-0.53	0	1	0 00	0.14	0 67	0 67

Site	Ft Lowell Elementary School 5151 E Pima (Between Swan and Craycroft) Tucson AZ 85712					Station / Vegetation / Description C-12 Bermuda grass N of Bldg W & S of Basketball courts										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-27-96	0 24	40	1	1	0.16	1 33	0 65	0 86	1 21	-0.34	0	1	0 00	0.16	0 50	0 50
10-4-96	0 24	40	1	1	0.16	1 58	0 65	1 03	0 00	1.03	0	1	0 00	0.16	-0 87	-0 87
10-11-96	0 24	40	1	1	0.16	1 64	0 65	1 07	0 00	1.07	0	1	0 00	0.16	-0 91	-0 91
10-19 96	0 24	40	1	1	0.16	1 50	0 65	0 97	0 04	0.93	0	1	0 00	0.16	-0 77	-0 77
10-26-96	0 24	40	1	1	0.16	1 40	0 65	0 91	0 00	0.91	0	1	0 00	0.16	-0 75	-0 75
11 2-96	0 24	40	1	1	0.16	0 71	0 65	0 46	0 99	-0.53	0	1	0 00	0.16	0 69	0 69

Site	Ft Lowell Elementary School 5151 E Pima (Between Swan and Craycroft) Tucson AZ 85712					Station / Vegetation / Description C-14 Bermuda grass E fence, N of Basketball courts										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req (in/read.)	# of Irrig Skipped	# of Irrig Since Last Reading	Water Saved (in/read.)	Irrig Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-27-96	0 24	40	1	1	0.16	1 33	0 65	0 86	1 21	-0.34	0	1	0 00	0.16	0 50	0 50
10-4-96	0 24	40	1	1	0.16	1 58	0 65	1 03	0 00	1.03	0	1	0 00	0.16	-0 87	-0 87
10-11-96	0 24	40	1	1	0.16	1 64	0 65	1 07	0 00	1.07	0	1	0 00	0.16	-0 91	-0 91
10-19-96	0 24	40	1	1	0.16	1 50	0 65	0 97	0 04	0.93	0	1	0 00	0.16	-0 77	-0 77
10-26-96	0 24	40	1	1	0.16	1 40	0 65	0 91	0 00	0.91	0	1	0 00	0.16	-0 75	-0 75
11-2-96	0 24	40	1	1	0.16	0 71	0 65	0 46	0 99	-0.53	0	1	0 00	0.16	0 69	0 69

Site	Ft Lowell Elementary School 5151 E Pima (Between Swan and Craycroft) Tucson AZ 85712					Station / Vegetation / Description C-17 Bermuda grass North, 3rd station from N fence										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig Skipped	# of Irrig Since Last Reading	Water Saved (in/read.)	Irrig Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-27-96	0 24	40	1	1	0.16	1 33	0 65	0 86	1 21	-0.34	0	1	0 00	0.16	0 50	0 50
10-4-96	0 24	40	1	1	0.16	1 58	0 65	1 03	0 00	1.03	0	1	0 00	0.16	-0 87	-0 87
10-11-96	0 24	40	1	1	0.16	1 64	0 65	1 07	0 00	1.07	0	1	0 00	0.16	-0 91	-0 91
10-19-96	0 24	40	1	1	0.16	1 50	0 65	0 97	0 04	0.93	0	1	0 00	0.16	-0 77	-0 77
10-26-96	0 24	40	1	1	0.16	1 40	0 65	0 91	0 00	0.91	0	1	0 00	0.16	-0 75	-0 75
11-2-96	0 24	40	1	1	0.16	0 71	0 65	0 46	0 99	-0.53	0	1	0 00	0.16	0 69	0 69

Site	Hudlow Elementary School 502 N Caribe Ave Tucson AZ 85710					Station / Vegetation / Description 7 Bermuda grass S cen yard, next to bldg on hill										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-27-96	0 25	40	1	1	0.17	0 38	0 65	0 25	1 21	-0.96	1	0	0 17	0.00	1 13	0 96
10-4-96	0 25	40	1	3	0.50	1 58	0 65	1 03	0 00	1.03	0	3	0 00	0.50	-0 53	-0 53
10-11-96	0 25	40	1	3	0.50	1 64	0 65	1 07	0 00	1.07	0	3	0 00	0.50	-0 57	-0 57
10-19-96	0 25	40	1	3	0.50	1 50	0 65	0 97	0 04	0.93	0	3	0 00	0.50	-0 43	-0 43
10-26-96	0 25	40	1	3	0.50	1 40	0 65	0 91	0 00	0.91	0	3	0 00	0.50	0 41	-0 41
11-2-96	0 25	40	1	3	0.50	0 71	0 65	0 46	0 99	-0.53	2	1	0 33	0.17	1 03	0 70
11 9 96	0 25	40	1	3	0.50	0 97	0 65	0 63	0 00	0.63	2	1	0 33	0.17	-0 13	-0 47
11 16 96	0 25	40	1	3	0.50	0 98	0 65	0 64	0 00	0.64	2	1	0 33	0.17	-0 14	-0 47

Site	Hudlow Elementary School 502 N Caribe Ave Tucson AZ 85710					Station / Vegetation / Description 13 Bermuda grass East yard										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl. (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-27 96	0 25	40	1	1	0.17	0 38	0 65	0 25	1 21	-0.96	1	0	0 17	0.00	1 13	0 96
10-4-96	0 25	40	1	3	0.50	1 58	0 65	1 03	0 00	1.03	0	3	0 00	0.50	-0 53	-0 53
10-11 96	0 25	40	1	3	0.50	1 64	0 65	1 07	0 00	1.07	0	3	0 00	0.50	-0 57	-0 57
10-19-96	0 25	40	1	3	0.50	1 50	0 65	0 97	0 04	0.93	0	3	0 00	0.50	-0 43	-0 43
10-26-96	0 25	40	1	3	0.50	1 40	0 65	0 91	0 00	0.91	0	3	0 00	0.50	0 41	-0 41
11 2 96	0 25	40	1	3	0.50	0 71	0 65	0 46	0 99	-0.53	0	3	0 00	0.50	1 03	1 03
11 9 96	0 25	40	1	3	0.50	0 97	0 65	0 63	0 00	0.63	0	3	0 00	0.50	-0 13	-0 13
11 16 96	0 25	40	1	3	0.50	0 98	0 65	0 64	0 00	0.64	0	3	0 00	0.50	-0 14	-0 14

Site	Hudlow Elementary School 502 N Caribe Ave Tucson AZ 85710					Station / Vegetation / Description 14 Bermuda grass East yard										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-27-96	0 25	40	1	1	0.17	0 38	0 65	0 25	1 21	-0.96	1	0	0 17	0.00	1 13	0 96
10-4-96	0 25	40	1	3	0.50	1 58	0 65	1 03	0 00	1.03	0	3	0 00	0.50	-0 53	-0 53
10-11-96	0 25	40	1	3	0.50	1 64	0 65	1 07	0 00	1.07	0	3	0 00	0.50	-0 57	-0 57
10-19-96	0 25	40	1	3	0.50	1 50	0 65	0 97	0 04	0.93	0	3	0 00	0.50	-0 43	-0 43
10-26-96	0 25	40	1	3	0 50	1 40	0 65	0 91	0 00	0.91	0	3	0 00	0.50	-0 41	-0 41
11-2-96	0 25	40	1	3	0.50	0 71	0 65	0 46	0 99	-0.53	2	1	0 33	0.17	1 03	0 70
11-9-96	0 25	40	1	3	0.50	0 97	0 65	0 63	0 00	0.63	1	2	0 17	0.33	-0 13	-0 30
11-16-96	0 25	40	1	3	0.50	0 98	0 65	0 64	0 00	0.64	2	1	0 33	0.17	-0 14	0 47

Site	Lawrence Park 6777 S Mark Rd Tucson AZ					Station / Vegetation / Description 3 Bermuda grass Left control box, west fence by parking										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0 47	32	1	5	1 25	1 57	0 65	1 02	0 00	1.02	2	3	0 50	0.75	0 23	-0 27
9-27-96	0 47	32	1	5	1.25	1 57	0 65	1 02	0 00	1.02	3	2	0 75	0.50	0 23	-0 52
10-2-96	0 47	21	1	3	0.49	1 11	0 65	0 72	0 00	0.72	1	2	0 16	0.33	-0 23	-0 39
10-11-96	0 47	21	1	7	1 15	2 11	0 65	1 37	0 00	1.37	6	1	0 99	0.16	0 22	-1 21
10-19-96	0 47	21	1	5	0.82	1 50	0 65	0 97	0 04	0.93	1	4	0 16	0.66	-0 11	-0 28
10-22-96	0 47	21	1	2	0.33	0 62	0 65	0 40	0	0.40	2	0	0 33	0.00	-0 07	-0 40

Site	Pima County Community Resources **Meadowbrook Park** 2635 W Sandbrooke Lane Tucson, AZ					**Station / Vegetation / Description** Station 1 Bermuda grass North side near slope											
Potential (Normal Timer) Irrigation Settings						**Irrigation Requirements**					**Overwatering Controller Data**				**Overwatering Occurances**		
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)	
Date	Station Appl (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement	
9-13-96	0 4	40	1	5	1.33	0 56	0 65	0 36	0 05	0.31	2	3	0 53	0.80	1 02	0 49	
9-20-96	0 4	40	1	5	1.33	1 57	0 65	1 02	0 00	1.02	1	4	0 27	1.07	0 31	0 05	
9-27-96	0 4	22	1	5	0.73	1 33	0 65	0 86	1 21	-0.34	1	4	0 15	0.59	1 08	0 93	
10-2-96	0 4	22	1	3	0.44	1 11	0 65	0 72	0 00	0.72	0	3	0 00	0.44	-0 28	-0 28	
10-4-96	0 4	22	1	2	0.29	0 47	0 65	0 31	0 00	0.31	0	2	0 00	0.29	-0 01	-0 01	
10-11-96	0 4	22	1	5	0.73	1 64	0 65	1 07	0 00	1.07	0	5	0 00	0.73	-0 33	-0 33	
10-19-96	0 4	22	1	5	0.73	1 50	0 65	0 97	0 04	0.93	0	5	0 00	0.73	-0 20	-0 20	
10-21-96	0 4	22	1	1	0.15	0 39	0 65	0 26	0 00	0.26	0	1	0 00	0.15	-0 11	-0 11	

Site	Pima County Community Resources **Meadowbrook Park** 2635 W Sandbrooke Lane Tucson, AZ					**Station / Vegetation / Description** Station 16 Bermuda grass East side near slope											
Potential (Normal Timer) Irrigation Settings						**Irrigation Requirements**					**Overwatering Controller Data**				**Overwatering Occurances**		
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)	
Date	Station Appl (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement	
9-13-96	0 4	40	1	5	1.33	0 56	0 65	0 36	0 05	0.31	3	2	0 80	0.53	1 02	0 22	
9-20 96	0 4	40	1	5	1.33	1 57	0 65	1 02	0 00	1.02	2	3	0 53	0.80	0 31	-0 22	
9-27-96	0 4	22	1	5	0.73	1 33	0 65	0 86	1 21	-0.34	1	4	0 15	0.59	1 08	0 93	
10-2-96	0 4	22	1	3	0.44	1 11	0 65	0 72	0 00	0.72	0	3	0 00	0.44	-0 28	-0 28	
10-4-96	0 4	22	1	2	0.29	0 47	0 65	0 31	0 00	0.31	0	2	0 00	0.29	-0 01	-0 01	
10 11 96	0 4	22	1	5	0.73	1 64	0 65	1 07	0 00	1.07	0	5	0 00	0.73	-0 33	-0 33	
10 19 96	0 4	22	1	5	0.73	1 50	0 65	0 97	0 04	0.93	0	5	0 00	0.73	0 20	-0 20	
10-21 96	0 4	22	1	1	0.15	0 39	0 65	0 26	0 00	0.26	0	1	0 00	0.15	-0 11	-0 11	

Site	Pima County Community Resources Mission Ridge Park 3300 W Tucker Rd Tucson, AZ					Station / Vegetation / Description Station 9 Bermuda grass West side, 3rd sta from school fence										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0 36	42	1	5	1.26	1 57	0 65	1 02	0 00	1.02	3	2	0 76	0.50	0 24	-0 52
9-27-96	0 36	42	1	5	1.26	1 57	0 65	1 02	0 00	1.02	4	1	1 01	0.25	0 24	-0 77
10-2-96	0 36	28	1	3	0.50	1 11	0 65	0 72	0 00	0.72	1	2	0 17	0.34	-0 22	-0 38
10-11-96	0 36	28	1	7	1.18	2 11	0 65	1 37	0 00	1.37	4	3	0 67	0.50	-0 20	-0 87
10-19-96	0 36	28	1	5	0.84	1 50	0 65	0 97	0 04	0.93	2	3	0 34	0.50	-0 09	-0 43
10-21-96	0 36	28	1	1	0.17	0 39	0 65	0 26	0 00	0.26	0	1	0 00	0.17	-0 09	-0 09

Site	Pima County Community Resources Mission Ridge Park 3300 W Tucker Rd Tucson, AZ					Station / Vegetation / Description Station 10 Bermuda grass West side, 2nd sta from school fence										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0 36	42	1	5	1.26	1 57	0 65	1 02	0 00	1.02	2	3	0 50	0.76	0 24	-0 27
9-27-96	0 36	42	1	5	1.26	1 57	0 65	1 02	0 00	1.02	3	2	0 76	0.50	0 24	-0 52
10-2-96	0 36	28	1	3	0.50	1 11	0 65	0 72	0 00	0.72	1	2	0 17	0.34	-0 22	-0 38
10-11-96	0 36	28	1	7	1.18	2 11	0 65	1 37	0 00	1.37	4	3	0 67	0.50	-0 20	-0 87
10-19-96	0 36	28	1	5	0.84	1 50	0 65	0 97	0 04	0.93	2	3	0 34	0.50	-0 09	-0 43
10-21-96	0 36	28	1	1	0.17	0 39	0 65	0 26	0 00	0.26	0	1	0 00	0.17	-0 09	-0 09

Site	Myers Ganoung Elementary School 5000 E Andrew (SE of 22nd and Swan) Tucson AZ 85711					Station / Vegetation / Description 13 Bermuda grass Clock #1 S side of building										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0 86	30	1	1	**0.43**	0 46	0 65	0 30	0 00	**0.30**	1	0	0 43	**0.00**	0 13	-0 30
9-27-96	0 86	30	1	3	**1.29**	1 33	0 65	0 86	1 21	**-0.34**	3	0	1 29	**0.00**	1 63	0 34
10-4-96	0 86	30	1	3	**1.29**	1 58	0 65	1 03	0 00	**1.03**	3	0	1 29	**0.00**	0 26	-1 03
10-11-96	0 86	30	1	3	**1.29**	1 64	0 65	1 07	0 00	**1.07**	0	3	0 00	**1.29**	0 22	0 22
10-19-96	0 86	30	1	3	**1.29**	1 50	0 65	0 97	0 04	**0.93**	0	3	0 00	**1.29**	0 36	0 36
10-26-96	0 86	30	1	3	**1.29**	1 40	0 65	0 91	0 00	**0.91**	0	3	0 00	**1.29**	0 38	0 38
11-2-96	0 86	30	1	3	**1.29**	0 71	0 65	0 46	0 99	**-0.53**	2	1	0 86	**0.43**	1 82	0 96
11-9-96	0 86	30	1	3	**1.29**	0 97	0 65	0 63	0 00	**0.63**	1	2	0 43	**0.86**	0 66	0 23
11 16-96	0 86	30	1	3	**1.29**	0 98	0 65	0 64	0 00	**0.64**	2	1	0 86	**0.43**	0 65	-0 21

Site	Myers Ganoung Elementary School 5000 E Andrew (SE of 22nd and Swan) Tucson AZ 85711					Station / Vegetation / Description 14 Bermuda grass Clock #1 SE side of building, sprinklers along bldg										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0 59	30	1	1	**0.30**	0 46	0 65	0 30	0 00	**0.30**	0	1	0 00	**0.30**	-0 00	-0 00
9-27-96	0 59	30	1	3	**0.89**	1 33	0 65	0 86	1 21	**-0.34**	0	3	0 00	**0.89**	1 23	1 23
10-4-96	0 59	30	1	3	**0.89**	1 58	0 65	1 03	0 00	**1.03**	3	0	0 89	**0.00**	-0 14	-1 03
10-11-96	0 59	30	1	3	**0.89**	1 64	0 65	1 07	0 00	**1.07**	0	3	0 00	**0.89**	-0 18	-0 18
10-19-96	0 59	30	1	3	**0.89**	1 50	0 65	0 97	0 04	**0.93**	0	3	0 00	**0.89**	-0 05	-0 05
10-26-96	0 59	30	1	3	**0.89**	1 40	0 65	0 91	0 00	**0.91**	0	3	0 00	**0.89**	-0 02	-0 02
11-2-96	0 59	30	1	3	**0.89**	0 71	0 65	0 46	0 99	**-0.53**	3	0	0 89	**0.00**	1 41	0 53
11 9 96	0 59	30	1	3	**0.89**	0 97	0 65	0 63	0 00	**0.63**	2	1	0 59	**0.30**	0 25	0 34
11 16 96	0 59	30	1	3	**0.89**	0 98	0 65	0 64	0 00	**0.64**	2	1	0 59	**0.30**	0 25	0 34

Site	Myers Ganoung Elementary School 5000 E Andrew (SE of 22nd and Swan) Tucson AZ 85711					Station / Vegetation / Description 1 Bermuda grass Clock #1 E fence, sprinklers along E fence (near bldg)										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0 59	30	1	1	**0.30**	0 46	0 65	0 30	0 00	**0.30**	0	1	0 00	**0.30**	0 00	0 00
9-27-96	0 59	30	1	3	**0.89**	1 33	0 65	0 86	1 21	**-0.34**	1	2	0 30	**0.59**	1 23	0 93
10-4-96	0 59	30	1	3	**0.89**	1 58	0 65	1 03	0 00	**1.03**	1	2	0 30	**0.59**	0 14	0 44
10-11-96	0 59	30	1	3	**0.89**	1 64	0 65	1 07	0 00	**1.07**	0	3	0 00	**0.89**	0 18	0 18
10-19-96	0 59	30	1	3	**0.89**	1 50	0 65	0 97	0 04	**0.93**	0	3	0 00	**0.89**	0 05	0 05
10-26-96	0 59	30	1	3	**0.89**	1 40	0 65	0 91	0 00	**0.91**	0	3	0 00	**0.89**	0 02	0 02
11-2-96	0 59	30	1	3	**0.89**	0 71	0 65	0 46	0 99	**-0.53**	3	0	0 89	**0.00**	1 41	0 53
11-9-96	0 59	30	1	3	**0.89**	0 97	0 65	0 63	0 00	**0.63**	1	2	0 30	**0.59**	0 25	0 04
11-16-96	0 59	30	1	3	**0.89**	0 98	0 65	0 64	0 00	**0.64**	1	2	0 30	**0.59**	0 25	0 05

Site	Myers Ganoung Elementary School 5000 E Andrew (SE of 22nd and Swan) Tucson AZ 85711					Station / Vegetation / Description 2 Bermuda grass Clock #1 E fence, sprinklers along N (3) & W (1) of co										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0 78	30	1	1	**0.39**	0 46	0 65	0 30	0 00	**0.30**	0	1	0 00	**0.39**	0 09	0 09
9-27-96	0 78	30	1	3	**1.17**	1 33	0 65	0 86	1 21	**-0.34**	1	2	0 39	**0.78**	1 51	1 12
10-4-96	0 78	30	1	3	**1.17**	1 58	0 65	1 03	0 00	**1.03**	3	0	1 17	**0.00**	0 14	-1 03
10-11-96	0 78	30	1	3	**1.17**	1 64	0 65	1 07	0 00	**1.07**	1	2	0 39	**0.78**	0 10	-0 29
10-19-96	0 78	30	1	3	**1.17**	1 50	0 65	0 97	0 04	**0.93**	3	0	1 17	**0.00**	0 24	-0 93
10-26-96	0 78	30	1	3	**1.17**	1 40	0 65	0 91	0 00	**0.91**	3	0	1 17	**0.00**	0 26	-0 91
11-2-96	0 78	30	1	3	**1.17**	0 71	0 65	0 46	0 99	**-0.53**	3	0	1 17	**0.00**	1 70	0 53
11-9-96	0 78	30	1	3	**1.17**	0 97	0 65	0 63	0 00	**0.63**	3	0	1 17	**0.00**	0 54	-0 63
11-16-96	0 78	30	1	3	**1.17**	0 98	0 65	0 64	0 00	**0.64**	3	0	1 17	**0.00**	0 53	-0 64

Site	Myers-Ganoung Elementary School 5000 E. Andrew (SE of 22nd and Swan) Tucson, AZ 85711					Station / Vegetation / Description 5 Bermuda grass Clock #1 E-SE fence, sprinklers around paved area											
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl. (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	2.45	30	1	1	**1.23**	0.46	0.65	0.30	0.00	**0.30**	1	0	1.23	**0.00**	0.93	-0.30
9-27-96	2.45	30	1	3	**3.68**	1.33	0.65	0.86	1.21	**-0.34**	3	0	3.68	**0.00**	4.02	0.34
10-4-96	2.45	30	1	3	**3.68**	1.58	0.65	1.03	0.00	**1.03**	3	0	3.68	**0.00**	2.65	-1.03
10-11-96	2.45	30	1	3	**3.68**	1.64	0.65	1.07	0.00	**1.07**	2	1	2.45	**1.23**	2.61	0.16
10-19-96	2.45	30	1	3	**3.68**	1.50	0.65	0.97	0.04	**0.93**	3	0	3.68	**0.00**	2.74	-0.93
10-26-96	2.45	30	1	3	**3.68**	1.40	0.65	0.91	0.00	**0.91**	3	0	3.68	**0.00**	2.77	-0.91
11-2-96	2.45	30	1	3	**3.68**	0.71	0.65	0.46	0.99	**-0.53**	3	0	3.68	**0.00**	4.20	0.53
11-9-96	2.45	30	1	3	**3.68**	0.97	0.65	0.63	0.00	**0.63**	3	0	3.68	**0.00**	3.04	-0.63
11-16-96	2.45	30	1	3	**3.68**	0.98	0.65	0.64	0.00	**0.64**	3	0	3.68	**0.00**	3.04	-0.64

Site	Las Palmas Apartments 6901 E Broadway (just West of Kolb) Tucson AZ 85710					Station / Vegetation / Description 2 Bermuda or Rye grass Front area by main office									Overwatering Occurances	
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data					
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9 27 96	1 49	17	1	2	0.84	0 38	0 75	0 29	1 21	-0.92	1	1	0 42	0.42	1 77	1 35
10 4 96	1 49	17	1	5	2.11	1 58	0 75	1 18	0 00	1.18	4	1	1 69	0.42	0 93	-0 76
10 11 96	1 49	17	1	5	2.11	1 64	0 75	1 23	0 00	1.23	2	3	0 84	1.27	0 88	0 04
10 19 96	1 49	17	1	5	2.11	1 50	0 75	1 12	0 04	1.08	1	4	0 42	1.69	1 03	0 60
10 26 96	1 49	17	1	5	2.11	1 40	0 75	1 05	0 00	1.05	1	4	0 42	1.69	1 06	0 64
11 2 96	1 49	17	1	5	2.11	0 71	0 75	0 53	0 99	-0.46	0	5	0 00	2 11	2 57	2 57

Site	Las Palmas Apartments 6901 E Broadway (just West of Kolb) Tucson AZ 85710					Station / Vegetation / Description 1 Bermuda or Rye grass East of pool, both sides of fence									Overwatering Occurances	
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data					
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9 27 96	1 6	16	1	2	0.85	0 38	0 75	0 29	1 21	-0.92	2	0	0 85	0.00	1 78	0 92
10 4 96	1 6	16	1	7	2.99	1 58	0 75	1 18	0 00	1.18	6	1	2 56	0.43	1 80	-0 76
10 11 96	1 6	16	1	7	2.99	1 64	0 75	1 23	0 00	1.23	3	4	1 28	1.71	1 76	0 48
10 19 96	1 6	16	1	8	3.41	1 50	0 75	1 12	0 04	1.08	1	7	0 43	2.99	2 33	1 90
10 26 96	1 6	16	1	7	2.99	1 40	0 75	1 05	0 00	1.05	1	6	0 43	2.56	1 94	1 51
11 2 96	1 6	16	1	7	2.99	0 71	0 75	0 53	0 99	-0.46	0	7	0 00	2.99	3 45	3 45

Site	Pima County Community Resources Richardson Park 3500 W Green Tree Dr Tucson, AZ					Station / Vegetation / Description Station 4 Bermuda grass Parallel to West fence										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-13-96	0 45	40	1	5	1.50	1 40	0 65	0 91	0 05	0.86	3	2	0 90	0.60	0 64	-0 26
9-18-96	0 45	40	1	3	0.90	1 11	0 65	0 72	0 00	0.72	2	1	0 60	0.30	0 18	-0 42
9-20-96	0 45	22	1	2	0.33	0 46	0 65	0 30	0 00	0.30	0	2	0 00	0.33	0 03	0 03
9-27-96	0 45	22	1	5	0.83	1 33	0 65	0 86	1 21	-0.34	2	3	0 33	0.50	1 17	0 84
10-4-96	0 45	22	1	5	0.83	1 58	0 65	1 03	0 00	1.03	2	3	0 33	0.50	-0 20	-0 53
10-11-96	0 45	22	1	5	0.83	1 64	0 65	1 07	0 00	1.07	3	2	0 50	0.33	-0 24	-0 74
10-17-96	0 45	22	1	4	0.66	1 35	0 65	0 88	0 04	0.84	1	3	0 17	0.50	-0 18	-0 34
10-21-96	0 45	5	1	2	0.08	0 78	0 65	0 51	0 00	0.51	0	2	0 00	0.08	-0 43	-0 43

Site	Pima County Community Resources Richardson Park 3500 W Green Tree Dr Tucson, AZ					Station / Vegetation / Description Station 5 Bermuda grass Parallel to West fence										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-13-96	0 45	40	1	5	1.50	1 40	0 65	0 91	0 05	0.86	3	2	0 90	0.60	0 64	-0 26
9-18-96	0 45	40	1	3	0.90	1 11	0 65	0 72	0 00	0.72	1	2	0 30	0.60	0 18	-0 12
9-20-96	0 45	22	1	2	0.33	0 46	0 65	0 30	0 00	0.30	0	2	0 00	0.33	0 03	0 03
9-27-96	0 45	22	1	5	0.83	1 33	0 65	0 86	1 21	-0.34	0	5	0 00	0.83	1 17	1 17
10-4-96	0 45	22	1	5	0.83	1 58	0 65	1 03	0 00	1.03	2	3	0 33	0.50	0 20	-0 53
10-11-96	0 45	22	1	5	0.83	1 64	0 65	1 07	0 00	1.07	3	2	0 50	0.33	-0 24	-0 74
10-17-96	0 45	22	1	4	0.66	1 35	0 65	0 88	0 04	0.84	1	3	0 17	0.50	-0 18	-0 34
10-21-96	0 45	5	1	2	0.08	0 78	0 65	0 51	0 00	0.51	0	2	0 00	0.08	-0 43	0 43

Site	Sunset Park (City Hall) 255 W Alameda Tucson AZ 85701					Station / Vegetation / Description S1 SE Buffalo Grass 2nd control box from east										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9 20 96	2	4	2	4	1.07	0 89	0 65	0 58	0 00	0.58	8	0	1 07	0.00	0 49	0 58
9 27 96	2	4	2	7	1.87	1 33	0 65	0 86	1 21	-0.34	6	8	0 80	1.07	2 21	1 41
10 2 96	2	4	2	5	1.33	1 11	0 65	0 72	0 00	0.72	6	4	0 80	0.53	0 61	0 19
10 4 96	2	4	2	2	0.53	0 47	0 65	0 31	0 00	0.31	4	0	0 53	0.00	0 23	0 31
10 11 96	2	4	2	7	1.87	1 64	0 65	1 07	0 00	1.07	2	12	0 27	1.60	0 80	0 53
10 19 96	2	4	2	8	2.13	1 50	0 65	0 97	0 04	0.93	10	6	1 33	0.80	1 20	0 13
10 26 96	2	4	2	7	1.87	1 40	0 65	0 91	0 00	0.91	10	4	1 33	0.53	0 96	0 38
11 2 96	2	4	2	7	1.87	0 71	0 65	0 46	0 99	-0.53	10	4	1 33	0.53	2 40	1 06
11 9 96	2	4	2	7	1.87	0 97	0 65	0 63	0 00	0.63	9	5	1 20	0.67	1 23	0 03
11 16 96	2	4	2	7	1.87	0 98	0 65	0 64	0 00	0.64	10	4	1 33	0.53	1 23	0 10

Site	Sunset Park (City Hall) 255 W Alameda Tucson AZ 85701					Station / Vegetation / Description S3 West Buffalo Grass 9th control box from east										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl. (in/hr)	Irrig Cycle Duration (min/irr)	Irrig. Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip. (in/read.)	Req. (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9 20 96	2	4	2	4	1.07	0 89	0 65	0 58	0 00	0.58	8	0	1 07	0.00	0 49	0 58
9 27 96	2	4	2	7	1.87	1 33	0 65	0 86	1 21	-0.34	5	9	0 67	1.20	2 21	1 54
10 2 96	2	4	2	5	1.33	1 11	0 65	0 72	0 00	0.72	6	4	0 60	0.53	0 61	0 19
10 4 96	2	4	2	2	0.53	0 47	0 65	0 31	0 00	0.31	4	0	0 53	0.00	0 23	0 31
10 11 96	2	4	2	7	1.87	1 64	0 65	1 07	0 00	1.07	3	11	0 40	1.47	0 80	0 40
10 19 96	2	4	2	8	2.13	1 50	0 65	0 97	0 04	0.93	9	7	1 20	0.93	1 20	0 00
10 26 96	2	4	2	7	1.87	1 40	0 65	0 91	0 00	0.91	11	3	1 47	0.40	0 96	0 51
11 2 96	2	4	2	7	1.87	0 71	0 65	0 46	0 99	-0.53	9	5	1 20	0.67	2 40	1 20
11 9 96	2	4	2	7	1.87	0 97	0 65	0 63	0 00	0.63	10	4	1 33	0.53	1 23	0 10
11 16 96	2	4	2	7	1.87	0 98	0 65	0 64	0 00	0.64	10	4	1 33	0.53	1 23	0 10

Site	Reid Park Zoo 1100 S Randolph Way Tucson AZ 85716					Station / Vegetation / Description 5 Lush long bermuda grass (rye in winter) Savanah (birds)										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig Days Since Last Reading	Irrig Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req. (in/read.)	# of Irrig Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0 39	10	2	3	0.39	0 66	0 65	0 43	0 00	0.43	6	0	0 39	0.00	-0 04	-0 43
9-27-96	0 39	10	2	7	0.91	1 33	0 65	0 86	1 21	-0.34	12	2	0 78	0.13	1 25	0 47
10-4-96	0 39	10	2	7	0.91	1 58	0 65	1 03	0 00	1.03	1	13	0 07	0.85	-0 12	-0 18
10-11-96	0 39	10	2	7	0.91	1 64	0 65	1 07	0 00	1.07	4	10	0 26	0.65	-0 16	-0 42
10-19-96	0 39	10	2	8	1.04	1 50	0 65	0 98	0 04	0.93	4	12	0 26	0.78	0 11	-0 15
10-26-96	0 39	10	2	7	0.91	1 40	0 65	0 91	0 00	0.91	5	9	0 33	0.59	0 00	-0 32
11-2-96	0 39	10	1	7	0.46	0 71	0 65	0 46	0 99	-0.53	0	7	0 00	0.46	0 98	0 98
11-9-96	0 39	10	1	7	0.46	0 97	0 65	0 63	0 00	0.63	0	7	0 00	0.46	-0 18	-0 18
11-16-96	0 39	10	1	7	0.46	0 98	0 65	0 64	0 00	0.64	0	7	0 00	0.46	-0 18	-0 18

Site	Reid Park Zoo 1100 S Randolph Way Tucson AZ 85716					Station / Vegetation / Description 2 Bermuda or Rye grass Giraffe display										
Potential (Normal Timer) Irrigation Settings						Irrigation Requirements					Overwatering Controller Data				Overwatering Occurances	
A	B	C	D	E	F (B*C*D*E/60)	G (AZMET)	H	I (G*H)	J (AZMET)	K (I - J)	L	M (D*E) - L	N (B*C*L/60)	O (B*C*M/60)	P (F - K)	Q (O - K)
Date	Station Appl (in/hr)	Irrig. Cycle Duration (min/irr)	Irrig Cycles per Day	Irrig. Days Since Last Reading	Irrig. Water Normally Applied (in/reading)	ETr (in/read.)	Kc	Eta (in/read.)	Precip (in/read.)	Req (in/read.)	# of Irrig. Skipped	# of Irrig. Since Last Reading	Water Saved (in/read.)	Irrig. Water Actually Applied (in/read.)	Timer Set Depth in Excess of Requirement	Actual Depth in Excess of Requirement
9-20-96	0 48	7	2	3	0.34	0 66	0 65	0 43	0 00	0.43	6	0	0 34	0.00	-0 09	-0 43
9-27-96	0 48	7	2	7	0.78	1 33	0 65	0 86	1 21	-0.34	3	11	0 17	0.62	1 13	0 96
10-4-96	0 48	7	2	7	0.78	1 58	0 65	1 03	0 00	1.03	5	9	0 28	0.50	-0 24	-0 52
10-11-96	0 48	7	2	7	0.78	1 64	0 65	1 07	0 00	1.07	0	14	0 00	0.78	-0 28	-0 28
10-19-96	0 48	7	2	8	0.90	1 50	0 65	0 98	0 04	0.93	0	16	0 00	0.90	-0 04	-0 04
10-26-96	0 48	7	2	7	0.78	1 40	0 65	0 91	0 00	0.91	0	14	0 00	0.78	-0 12	-0 12
11-2-96	0 48	7	1	7	0.39	0 71	0 65	0 46	0 99	-0.53	7	0	0 39	0.00	0 92	0 53
11-9-96	0 48	7	1	7	0.39	0 97	0 65	0 63	0 00	0.63	0	7	0 00	0.39	-0 24	-0 24
11-16-96	0 48	7	1	7	0.39	0 98	0 65	0 64	0 00	0.64	0	7	0 00	0.39	-0 25	-0 25

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